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VISUAL AND SCANNING ELECTRON MICROSCOPY INVESTIGATION AND TENSILE TESTING TO ESTIMATE RESIDUAL TENSILE STRENGTH OF A SELECTION OF LOBSTER LINES

For

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1 EXECUTIVE SUMMARY

The results of visual examination, scanning electron microscopy [SEM] and tensile testing of dissected ropes sent to TTI are described in this report. The ropes are divided into three general constructional types:

1. A construction where polypropylene [PP] filaments dominate the outer face of the strands from which the ropes are made, ‘Anacko Neutral Buoyant’
2. Two constructions where the outer face of the strands consists of a blend of PP and polyester filaments, Everson 3- strand Neutral Buoyancy and Everson 4-strand Sink.
3. Two constructions where polyester filaments dominate the outer face, Orion Orco Sink and Polysteel Atlantic Ester Pro Sink

The ropes had experienced different numbers of hauls and had been deployed in differing locations and this must be borne in mind when considering the results. In general, external abrasion was the dominant fatigue mechanism. Internal abrasion and the effect of pressure on both types of filament was also seen. The PP filaments were found to be more sensitive to pressure than the polyester filaments. Some limited abrasion damage due to particle penetration was also seen in some of the ropes, but its effect would be very small when compared to that of the abrasion damage.

From the visual and SEM investigation it may be concluded that rope constructions, where PP and polyester filaments are present as a blend in the surface layer of rope strands, have good resistance to external and internal abrasion. The Everson ropes were constructed in this way. A rope construction where PP filaments dominate the outer layer, Anacko, suffered high levels of mechanical damage.

The results for the two ropes where polyester filaments dominate the outer face were mixed. The Orco specification suffered from the effects of abrasion and pressure to a greater extent than did the Ester Pro specification and also displayed a greater degree of filament abrasion damage due to particle penetration. In general, the Ester Pro compared well with the two Everson specifications, where the outer face is a blend of PP and polyester filaments.

It was noticed that the field tested Orco specification differed from that which was used for whole rope testing of machine abraded samples. The field tested rope appeared to have more polyester filaments in the construction, and their diameter appeared to be different. Reports from the vessel that used this rope were not very good either, despite the fact that TTI are not aware of any similar criticism of the rope when being machine abraded.

Tensile testing of rope strands, showed that the Everson and Polysteel specifications had estimated % Residual Strengths of between 75-80%. The Anacko specification was just below 70%, whilst the Orco had declined to just below 52%.

The results of the machine abraded whole rope tensile testing showed a similar trend for all the ropes except for Orco. The Everson and Polysteel specifications were between 54-60% residual Strength, whilst the Anacko was at just below 47% Residual Strength.

The Orco machine abraded rope had a % Residual Strength of just below 55%, ie in line with the Everson and Polysteel results. This is a further indication that something unusual has happened with the Orco field rope.

The difference between the field abraded and machine abraded Residual Strengths is expected, as the DMF have confirmed that the machine abraded tests were designed to simulate usage over an extended period of time, whereas the field abraded ropes had only been exposed to a limited number of hauls.

2 INTRODUCTION

An initial set of 5 ropes were sent to TTI Ltd in the UK for visual and microscopic inspection and tensile testing. The ropes were all withdrawn from use after a short-term deployment within the fishing grounds, for laboratory investigation. The intended useful lifetime is about 5 years.

The ropes were identified as:

1. **Code L10, Anacko 3-strand 'Neutral Buoyant'**
2. **Code L1, Everson 3-strand 'Neutral Buoyancy',**
3. **Code L2, Everson 4-strand 'Sink'**
4. **Code L13, Orion Orco 3-strand 'Sink'**
5. **Code L16, Polysteel 3-strand Ester Pro 'Sink'**

1 GENERAL ROPE DESCRIPTION and BACKGROUND INFORMATION

Table 1 shows the rope samples received.

Table 1 samples received

Rope	Field	New
Anacko, L10	yes	no
Everson, L1	yes	yes
Everson, L2	yes	yes
Orion, L13	yes	no
Polysteel, L16	yes	yes

Table 2 gives some general information regarding the construction of the ropes examined. It includes data provided by DMF.

Table 2 General information, field ropes

Rope	Strands	Inner YPS	Outer YPS	SG ex DMF	Lay angle ^{0}	Ave dia Inches [% increase over new]	No of hauls	Comments from field
Anacko, L10	3	2[3?]	8[7?]	1.033	34	0.85 [N/A]	55	Set mainly on hard bottom. No other comments noted
Everson, L1	3	5	14	1.073	25	0.71 [-1.5%]	31	Well liked by crew. Set generally on hard bottom
Everson, L2	4	5	10	1.084	34	0.81 [0%]	43	Set mainly on mud/gravel bottom. No other comments noted
Orion, L13	3	3	8	1.091	40	0.85 [N/A]	28	Not liked by crew. Set mainly on hard bottom but moved onto sandier bottom
Polysteel, L16	3	4	10	1.126	39	0.78 [+9%]	43	Set mainly on mud/gravel bottom. No other comments noted.

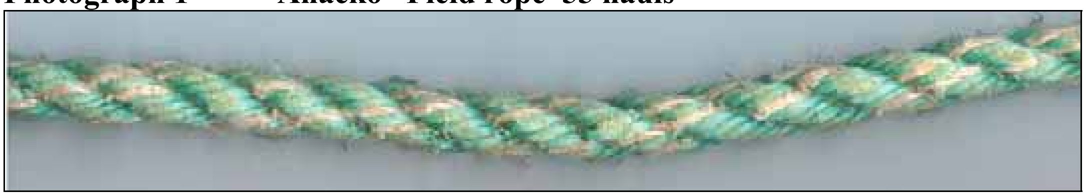
Yarn counts of the strands between inner and outer layers could be +/-1, due to the possibility of migration. DMF report that Specific Gravity, SG, could vary within any one rope type and that they considered the information not very reliable. The only rope to attract adverse comment from the field was the Orion Orco, L13, whilst the Everson 3-strand, L1, attracted positive comment.

2 VISUAL and MICROSCOPIC INSPECTION

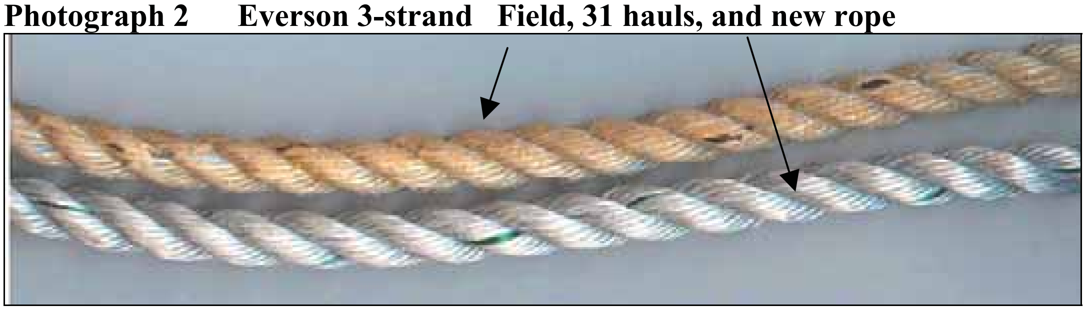
2.1 General views of ropes

Photographs 1-5 show general views of the ropes submitted to TTI for further investigation.

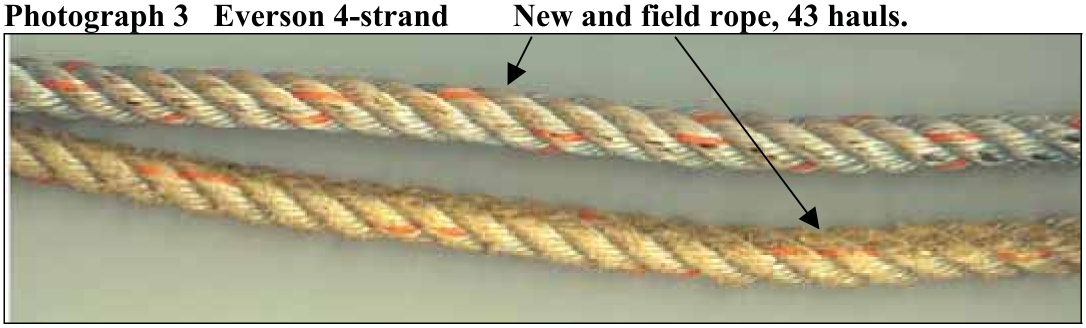
Photograph 1 Anacko Field rope 55 hauls



Photograph 2 Everson 3-strand Field, 31 hauls, and new rope

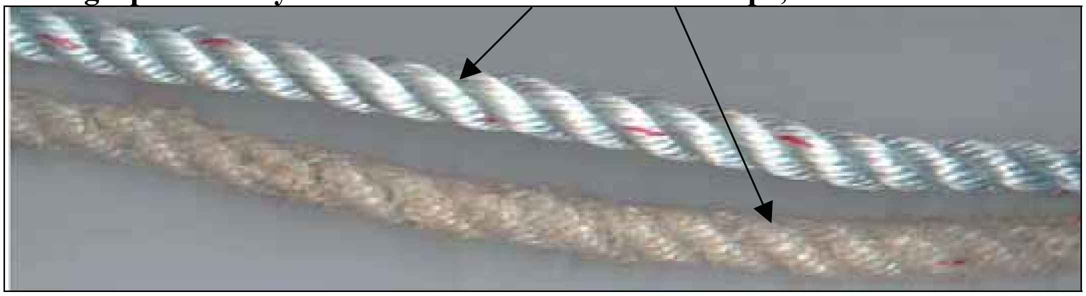


Photograph 3 Everson 4-strand New and field rope, 43 hauls.



Photograph 4 Orion Orco Field rope, 28 hauls

Photograph 5 Polysteel Ester Pro New and field rope, 43 hauls.



All the ropes were in a clean condition with little particle contamination released during handling and dissection. The ropes were not dissected down to their component rope or textile yarns as little extra information would be gained from this. The visual and tensile investigations were therefore conducted on the component strands of each rope.

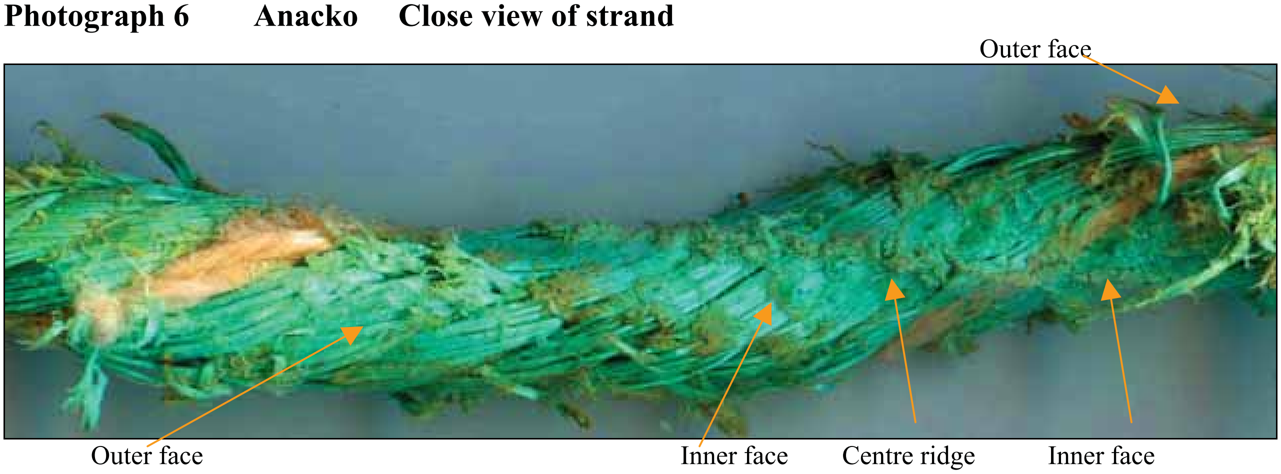
The field Anacko rope is seen to have broken filament material protruding from its surface. The field Polysteel Ester Pro has lost much of its surface appearance due to abrasion of the yarns at the surface. However, all the field ropes have suffered external abrasion, this being evenly distributed along the length and around the circumference of each of the ropes samples. The ropes did not show any signs of localized enhanced damage and no other unusual features were seen.

2.2 Individual rope strand inspection

This section contains general optical and a selection of SEM images of the field ropes, to present an overview of how each of them has responded to deployment in the field. Further images are shown in Section 3.3

2.2.1 Anacko field rope, 55 hauls

Photograph 6 Anacko Close view of strand

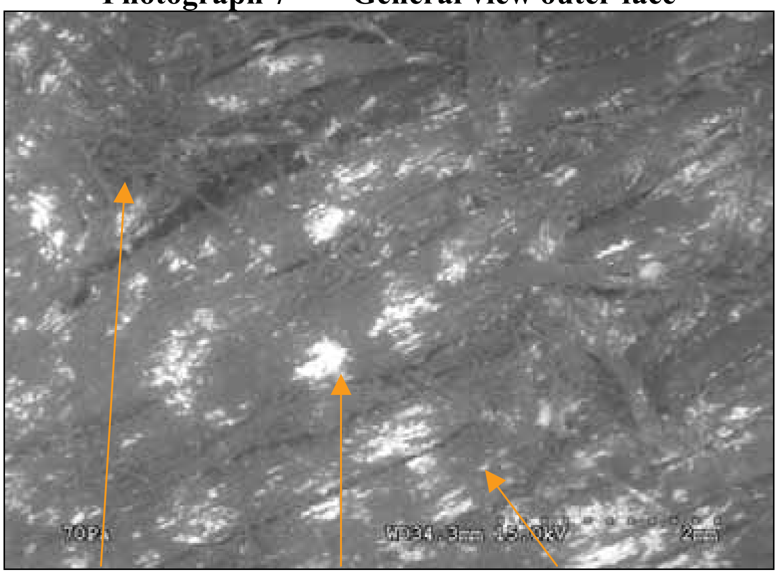


The outer layer of the strand is composed of rope yarns made from PP filaments. A polyester rope yarn also appears on the surface. The core rope yarns are from polyester filaments. Much abrasion damage is seen to the outer face of the strand, it being a combination of broken PP filaments and fibrillated PP debris. Some damage is also seen to the polyester rope yarn. The inner face has a more polished appearance but with fibrillated material at the centre ridge. This ridge lies in the space between the two partner strands of the rope construction.

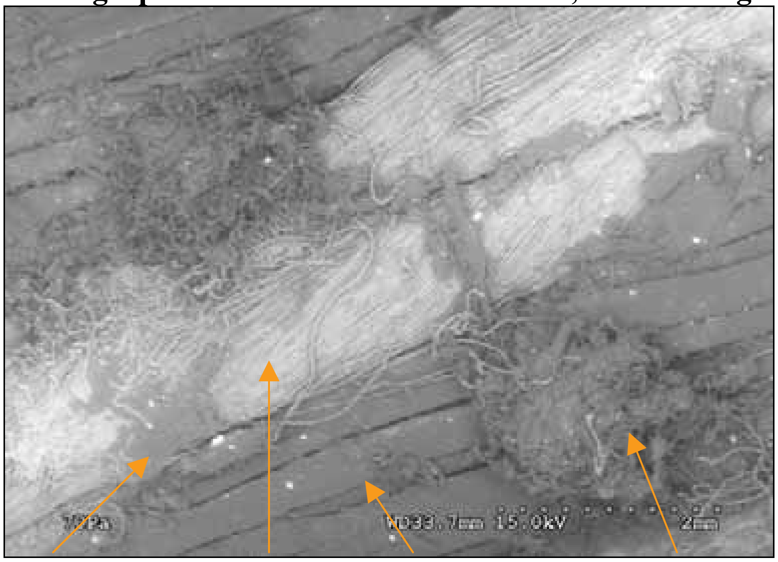
Clearly, from the broken filaments and fibrillated debris seen on the outer face, external abrasion damage is the dominant wear mechanism. This rope has had the greatest number of hauls of the five types inspected, at 55.

Photographs 7 and 8 are low magnification SEM views of the outer and inner faces of the strand.

Photograph 7 General view outer face



Photograph 8 General view inner face, close to ridge



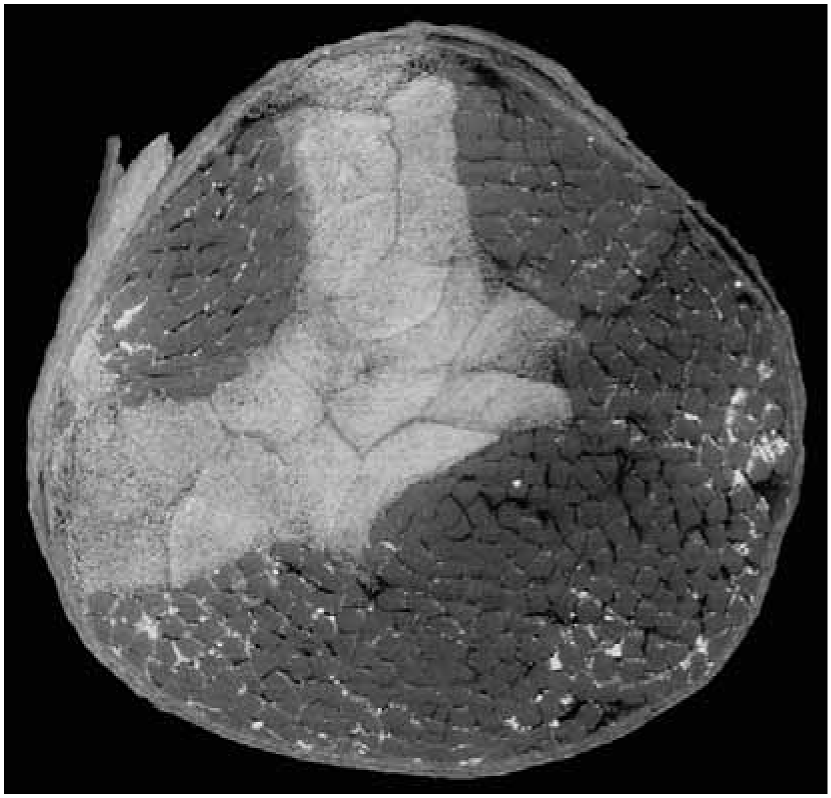
Fused PP Polyester filaments Flattened PP Abraded PP

The outer face has much fibrillated polypropylene debris, the result of external abrasion. Particle contamination is seen as the white areas in the image.

The inner face shows evidence of the polypropylene having been subjected to pressure as well as internal abrasion, the evidence of pressure being seen as a flattening of the surfaces of the filaments. Also, there are patches of the [darker] abraded polypropylene material that have been fused together , further evidence of the effect of pressure on the polypropylene component of the rope.

Photograph 9 shows a cross-section of the strand. All the cross-sections were prepared by binding a strand as tightly as possible with tape and then cold-cutting with a clean scalpel blade.

Photograph 9
General view of a cross-section of the strand



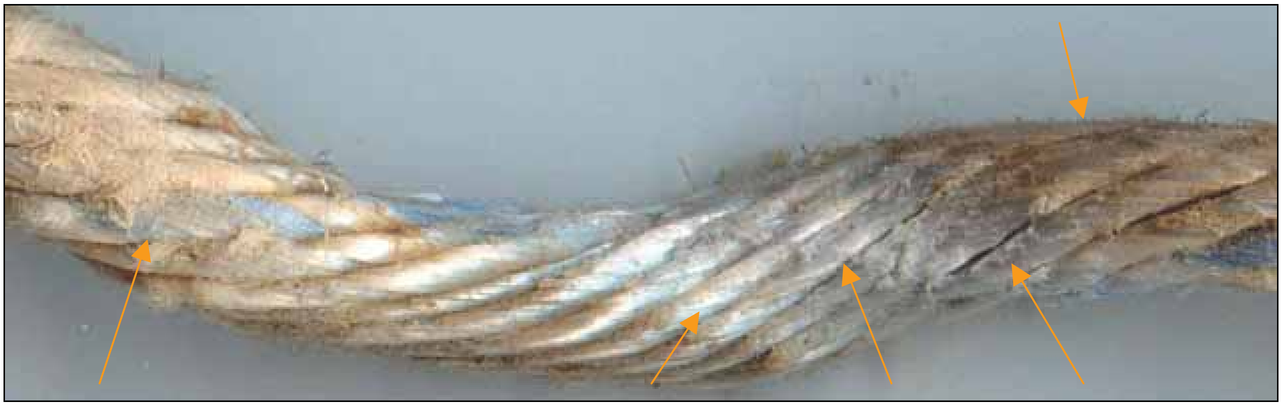
Both the polypropylene and polyester components of the strand are clearly seen. The outer surface of the rope strand is seen to be mostly of polypropylene rope yarns/filaments, with the polyester yarns lying mainly in the inner part of the strand. The polyester filaments are seen to be closely packed with no gaps, whereas the PP yarns have larger gaps between them. These gaps will make it easier for particles to migrate through the strand.

Particle contamination is seen in white. Particle contamination is seen to track through the polyester filaments where polyester yarn has appeared on the surface. However, the polypropylene yarns/filaments have suffered the majority of the contamination. The contamination is dispersed around the cross-section but with higher concentrations being seen in the lower half of the cross-section.

Closer views and further analysis of this and the other ropes will be presented in the following section of this report.

2.2.2 Everson 3-strand field rope, 31 hauls

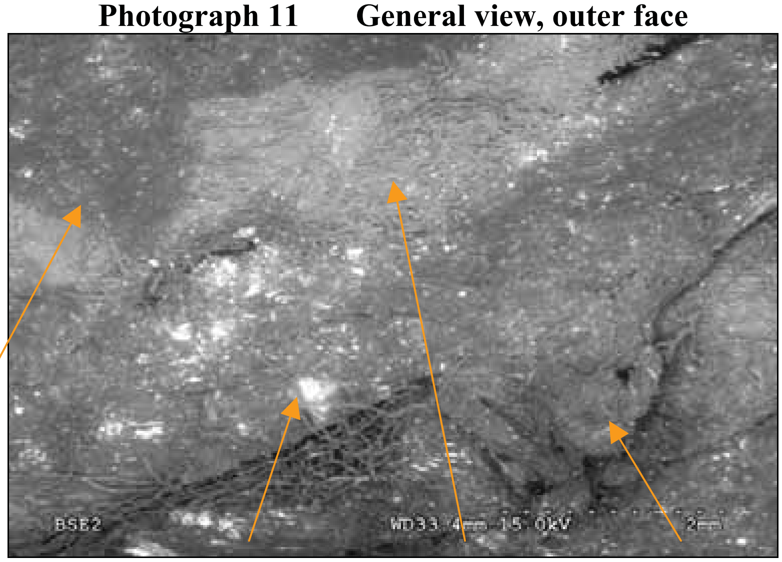
Photograph 10 Everson 3-strand close view of strand



The rope strands of this rope consist of an outer layer of rope yarns that are blends of polyester and PP filaments. The core textile yarns are made from PP filaments. External and internal abrasion and particle contamination is seen. The [blue] polypropylene filaments are not showing the same degree of actual failure when compared to the Anacko rope and in general the overall wear is less than that of the Anacko rope.

Photographs 11 and 12 are low magnification views of the outer and inner faces.

Photograph 11 General view, outer face



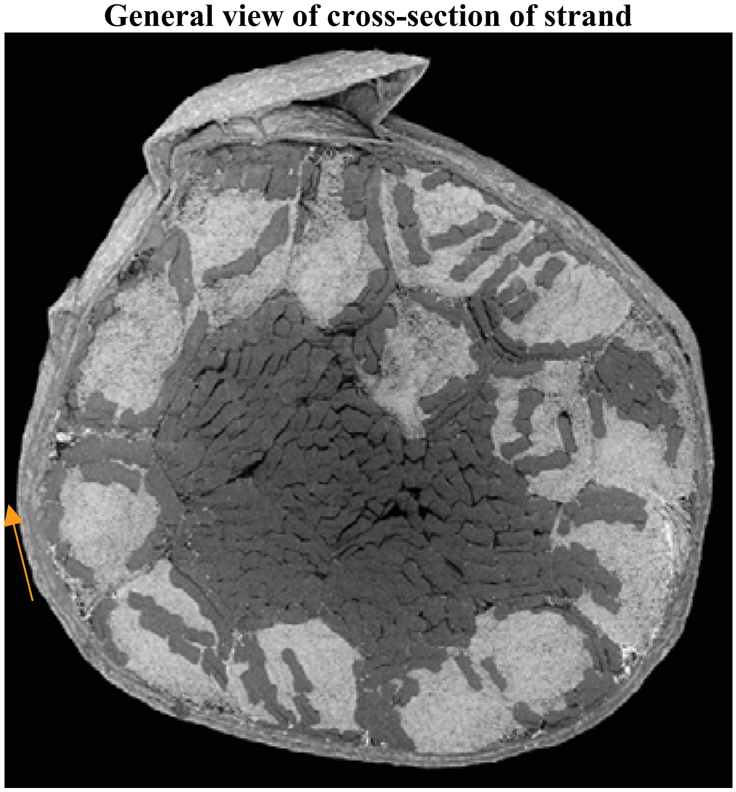
The outer surface is showing clear evidence of pressure damage where polypropylene material is seen to have flattened/flowed around polyester filaments, these in turn also displaying pressure induced flattening.

Photograph 12 General view inner face, close to ridge

This image shows both polypropylene and polyester material. Evidence of pressure flattening/flowing is seen, as is some internal abrasion damage.

Photograph 13 is a view of the cross-section of a strand.

Photograph 13
General view of cross-section of strand

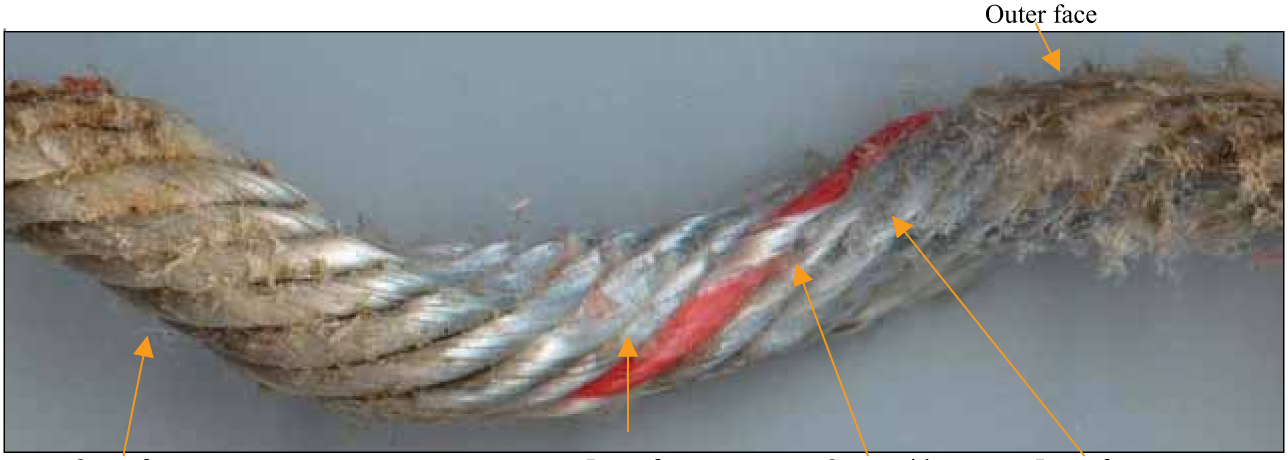


The structure of the strand is seen, where the rope yarns of the outer layer are made up of a blend of polypropylene and polyester filaments. The general arrangement of these rope yarns appears to be that the polypropylene filaments surround the polyester filaments, though inevitably there is migration of the two materials. There is a core of inner rope yarns are made up exclusively of polypropylene yarns/filaments, but some polyester/PP blended rope yarns also appear in the inner structure of the strand.

Particle migration into the inner structure of the strand is relatively mild and a migration route is seen around the boundaries between adjacent rope yarns. Little particle migration is seen within the polyester and polypropylene yarns/filaments.

2.2.3 Everson 4-strand field rope, 43 hauls

Photograph 14 Everson 4-strand close view

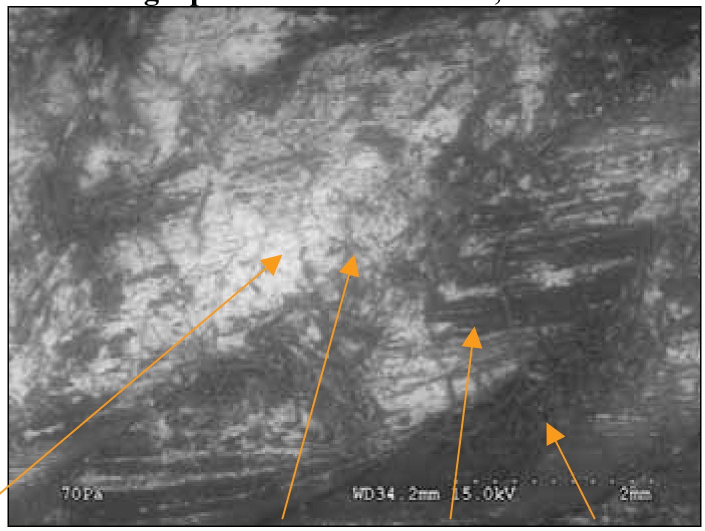


The rope strands of this rope consist of an outer layer of yarns that are blends of polyester and PP filaments. This is the same as for the Everson 3-strand construction. There are also 100% PP yarns in the core of the strand, though the strand assembly does not appear to be as regular as that seen in the 3-strand rope.

The strand in this view shows external abrasion at a higher level than for Everson 3-strand and is probably related to an increased number of hauls. The centre ridge is less prominent than for the 3-strand construction, the cause of this being most likely due to loading being distributed over 4 strands rather than 3.

Photograph 15 shows an SEM view of the outer surface of the strand

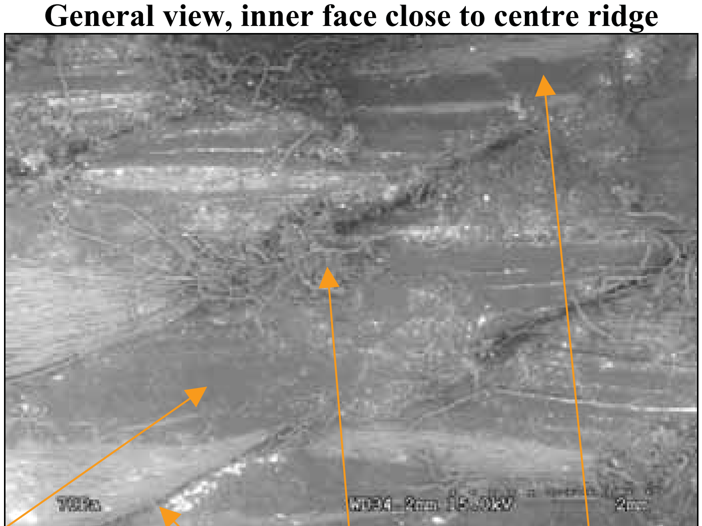
Photograph 15 General view, outer face



In this view, the outer surface is seen to be heavily contaminated with sediment, with abraded material protruding through it. The underlying structure of polypropylene filaments can be seen as well as disturbed polyester filaments.

Photograph 16 shows the inner face.

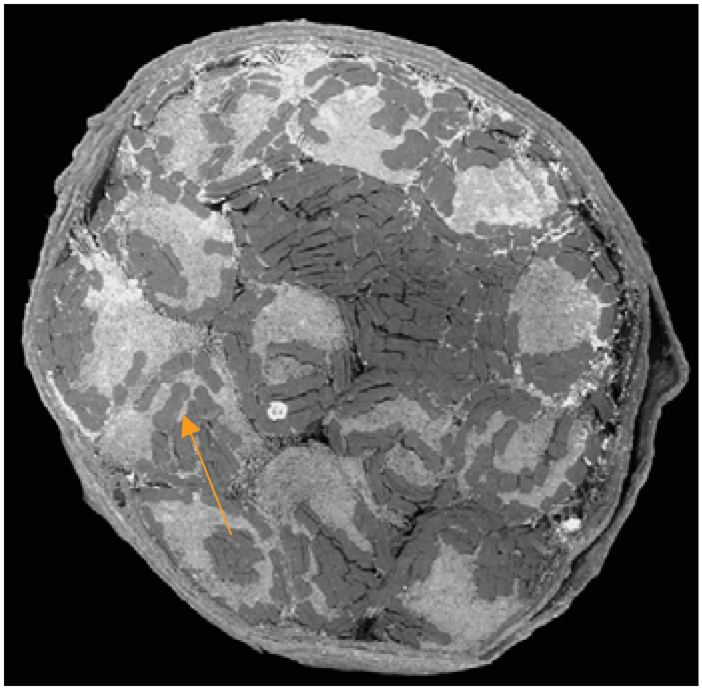
Photograph 16
General view, inner face close to centre ridge



Contamination is much reduced compared to the outer face, but debris from internal abrasion is seen. Some evidence of pressure-induced flow of polypropylene is also seen.

Photograph 17 shows a view of the cross-section

Photograph 17
General view of cross-section



The structure of the rope yarns in the outer layer is the same as for the 3-strand construction, with a general arrangement of polypropylene filaments wrapped around polyester filaments. This type of rope yarn is also seen in the inner structure of the strand. There is also an inner assembly exclusively of polypropylene filaments.

Significant particle contamination is seen in the upper half of the cross-section and, in general, the level of contamination and penetration is higher than for the 3-strand construction. However, this may well be due to a greater number of hauls rather than due to differences in construction. Particle contamination appears to follow the boundaries between adjacent rope yarns

The blending of polyester and PP filaments in yarns located in the outer layer of strands appears to have the benefit of good abrasion resistance. This is in line with what was found during the development of mixed filament ropes for vessel moorings, in that the most wear resistant ropes were made with blended yarns of polyester and PP. Using outer yarn assemblies of 100% polyester or 100% PP yarns, as with the Anacko, Orion and Polysteel constructions, were found to be less wear resistant.

2.2.4 Orion Orco field rope, 28 hauls

Photograph 18 Orion Orco Close view of strand

The strands of this rope is an assembly of yarns that have outer polyester filaments around a core of PP filaments. Both internal and external abrasion damage is clearly seen and is severe given the low number of hauls. One rope yarn appears to have suffered excessive external abrasion, resulting in severe loss of polyester filaments and the consequent exposure of blue PP filaments.

Photograph 20 is a low magnification view of the outer face.

Photograph 19 General view outer face

Only the polyester yarns/filaments are seen. Abrasion damage and flattening of filaments is seen, as well particle contamination.

Photograph 21 shows the inner face.

Photograph 21 General view of inner face, ridge area

Whilst pressure flattening is seen, it is at a reduced level when compared to the outer face. Contamination is seen, but also at a reduced level when compared to the outer face.

A sample of machine tested rope was also sent for examination. Photographs 22a and b compare the visual appearance of the two ropes.

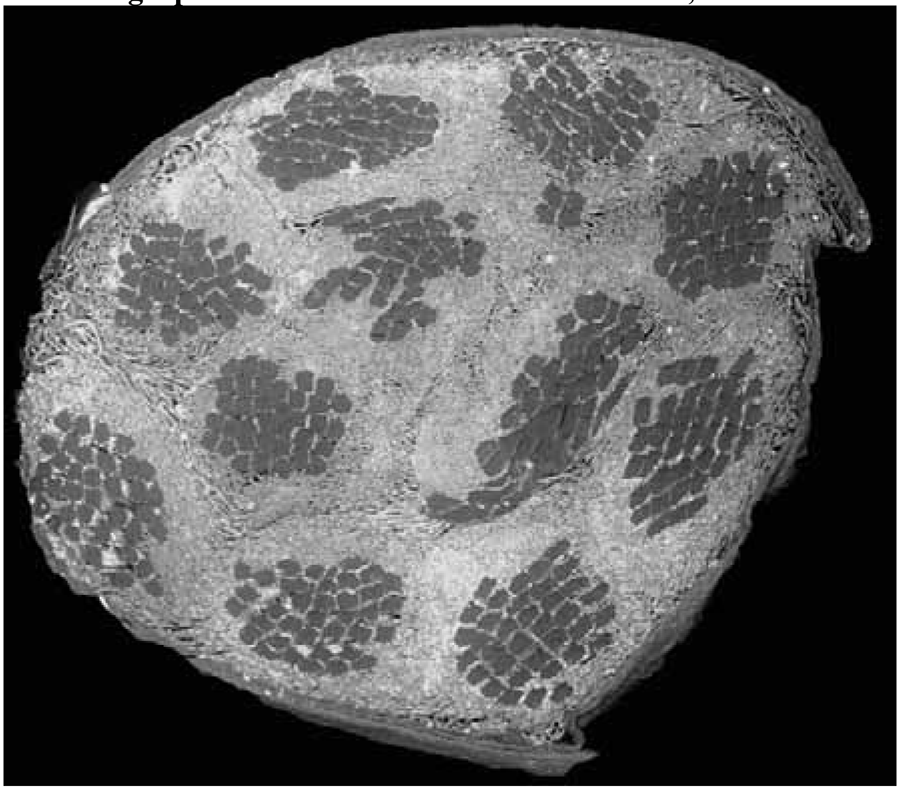
Photograph 22a   Orion Orco field tested 28 hauls

Photograph 22b   Orion Orco machine tested

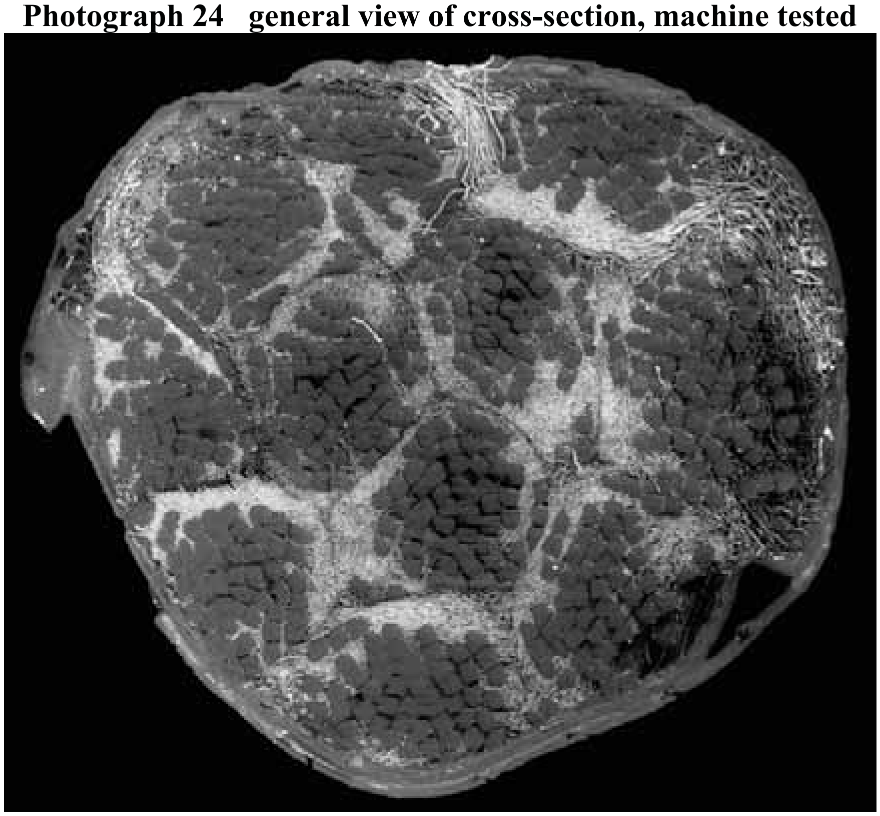
Photographs 23 shows views of the cross-section of the field rope, whilst Photograph 24 shows a cross-section of a machine tested sample.

It may be seen that the two cross-sections appear to be different in that the field sample has more polyester filaments of [probably] thicker cross-section than does the machine tested sample.

Photograph 23 General view of cross-section, field tested



Photograph 24 general view of cross-section, machine tested



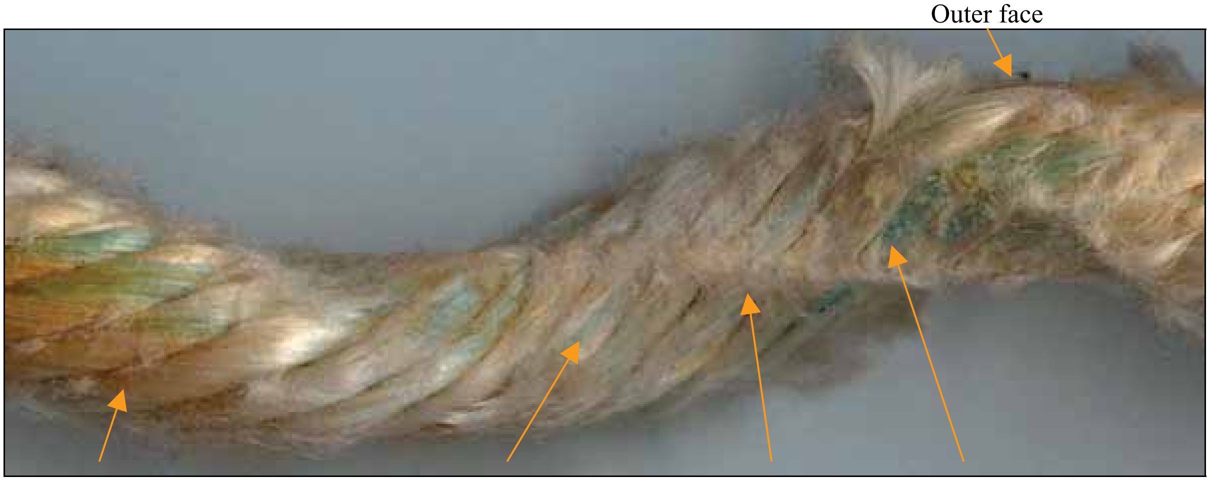
From inspection of Photograph 23, it can be seen that the rope yarns are an outer assembly of polyester yarns surrounding an inner assembly of polypropylene yarns. Particle penetration is high when the relatively low number of hauls [28] is taken into account.

The visual and SEM evidence shows that this rope design, with polyester filaments dominating the outer surfaces of the strands, was less resistant to abrasion than the Everson designs, where PP filaments appeared on the surface of the strands in conjunction with polyester filaments. Also, the degree of particle contamination is high given that part of its deployment was in a ‘hard’ bottom region where it would be expected that sand/mud would be not very prevalent.

The field rope was not well received by the fishermen, though there has been no report to TTI that the machine tested rope caused problems. This might be explained by the apparent difference in construction and supports the idea that where PP filaments are on the rope surface in association with polyester filaments [as with the machine tested sample], then better all-round performance is experienced.

2.2.5 Polysteel Ester Pro field rope, 43 hauls

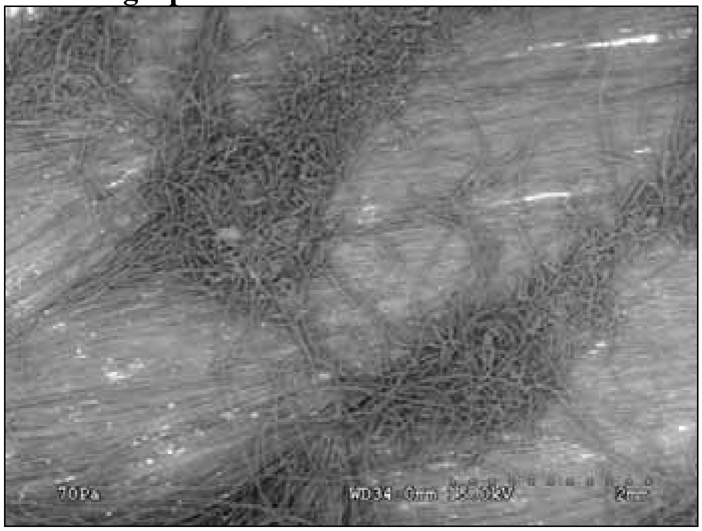
Photograph 25 Polysteel Ester Pro, close view of strand



The outer surface of this rope is primarily polyester yarns/filaments, with the [green] polypropylene yarns/filaments being exposed by a combination of migration and abrasion.

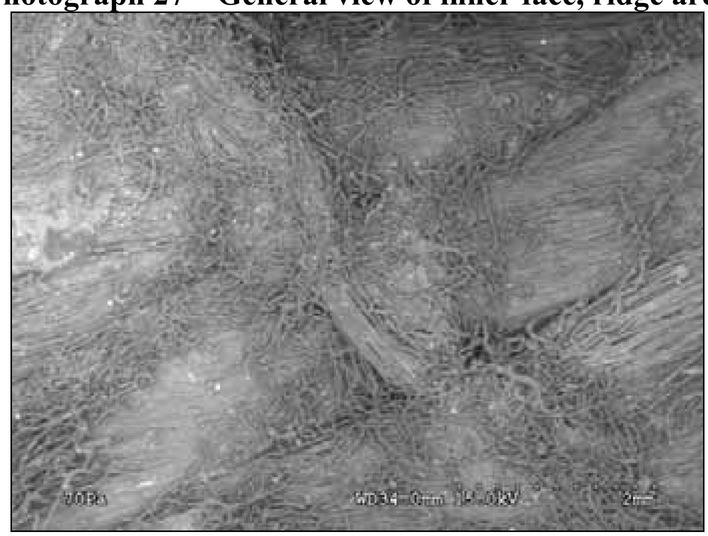
Photographs 26 and 27 show the outer and inner faces respectively.

Photograph 26 General view of outer face



Whilst external abrasion damage is seen, pressure flattening is relatively mild.

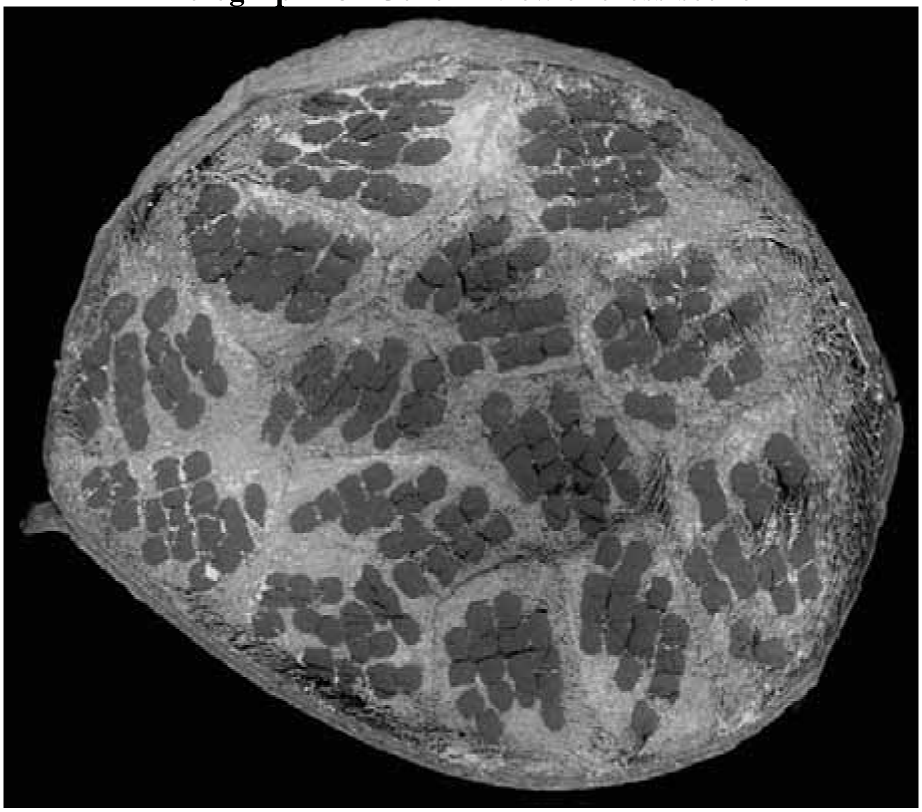
Photograph 27 General view of inner face, ridge area



Internal abrasion damage is seen, as is a higher degree of pressure flattening when compared to the outer face.

Photographs 28 shows view of the cross-section.

Photograph 28   General view of cross-section



As with the Orion Orco rope, all the rope yarns are blends of PP and polyester filaments, with the PP filaments arranged as a core. However, the PP filaments are more loosely arranged than the Orco rope yarns, with a greater tendency for the polyester filaments to intermingle with them.

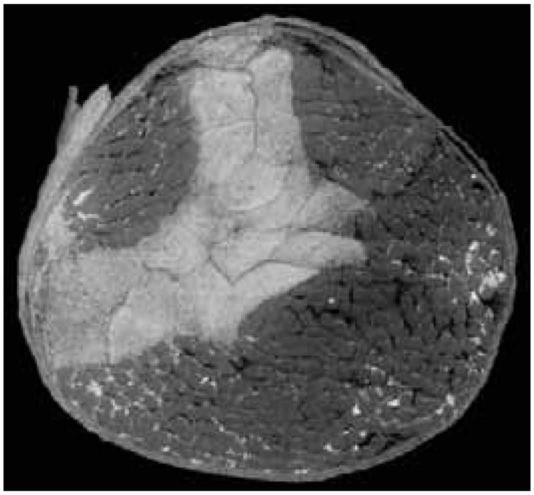
Particle penetration is seen predominantly in the polyester filaments, but migration into the polypropylene filaments is also seen.

Photograph 27 shows a selection of cross-section views of all the ropes, to allow an overview of the differences in construction and the degree of particle penetration.

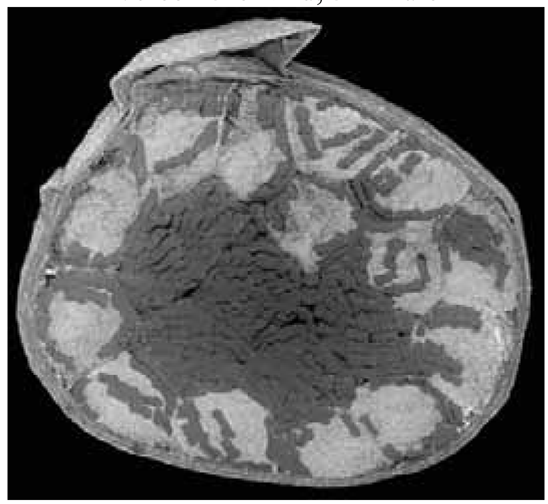
Although there are differences in the number of hauls and the environments in which the lines were used, the visual and SEM investigations show that ropes where there are both PP and polyester fibres on the surface of the strands have a good balance of resistance to abrasion and particle penetration.

Photograph 27

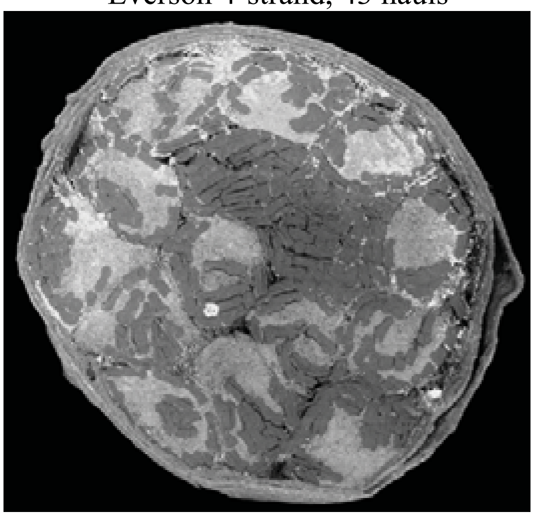
Anocko, 55 hauls



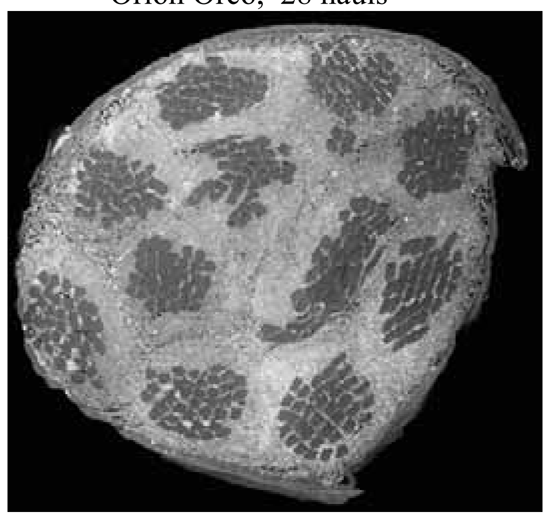
Everson 3-strand, 31 hauls



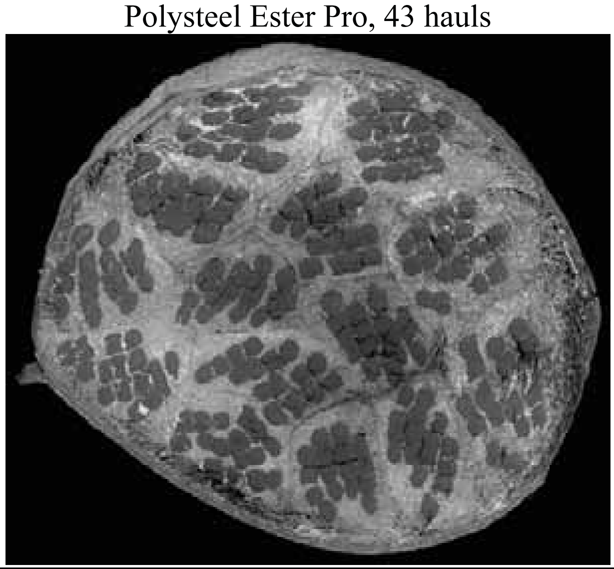
Everson 4-strand, 43 hauls



Orion Orco, 28 hauls



Polysteel Ester Pro, 43 hauls



Whilst the number of hauls and the field conditions have varied between the rope types, there is good evidence to support the conclusion that where PP and polyester filaments are present in the outer face of the rope strands, then abrasion resistance is better and particle penetration is reduced.

The dominant fatigue mechanisms are external and internal abrasion with associated pressure damage particularly to the PP filaments. Whilst particle penetration has occurred in all the ropes to varying degrees, only a small amount of abrasion damage, as a result of this penetration, is seen.

Whilst evidence of pressure damage is seen from surface views, the cross-sections reveal that this damage does not extend into the inner structure of the strands.

2.3 Further SEM images at higher magnification and X-Ray Spectra

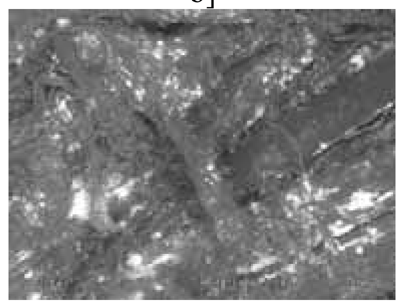
2.3.1 Anacko field rope, 55 hauls

Photograph 28

Further surface views, Anacko outer face

a]

b]



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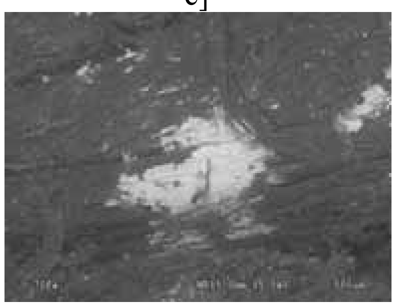

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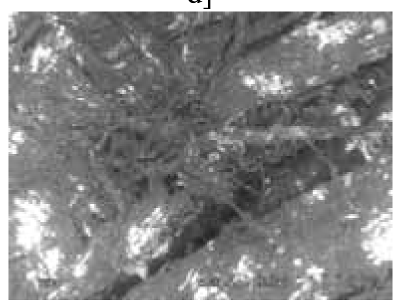
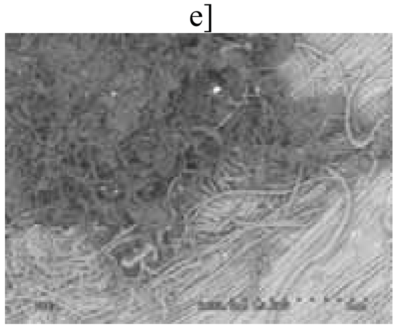


Further surface views, Anacko inner face

e]



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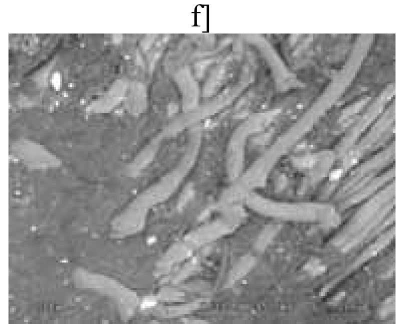
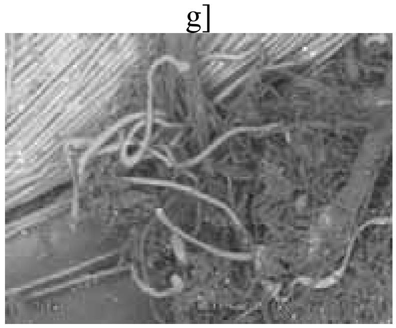
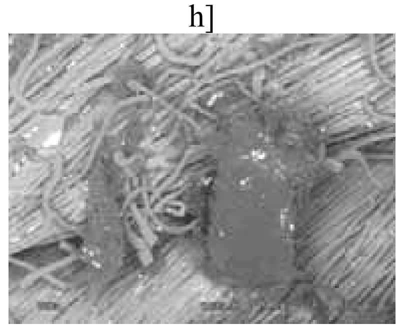


g]



h]

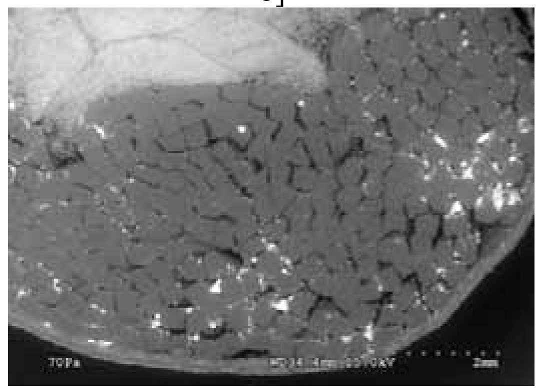


Photograph 29

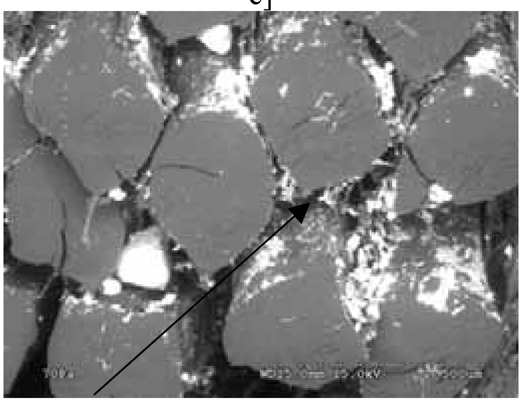
Further cross-section views, Anacko

a]

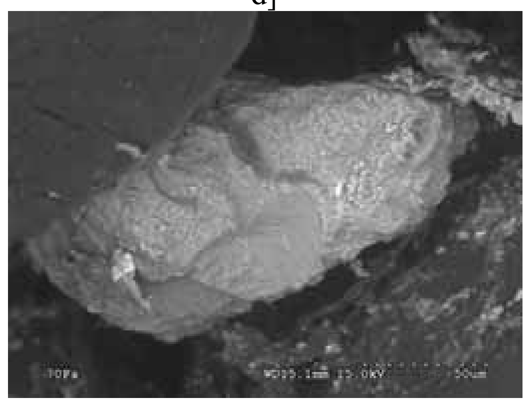
b]



c]

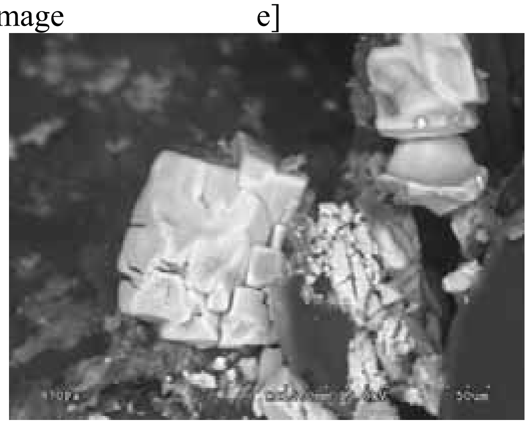


d]



PP filament abrasion damage

e]

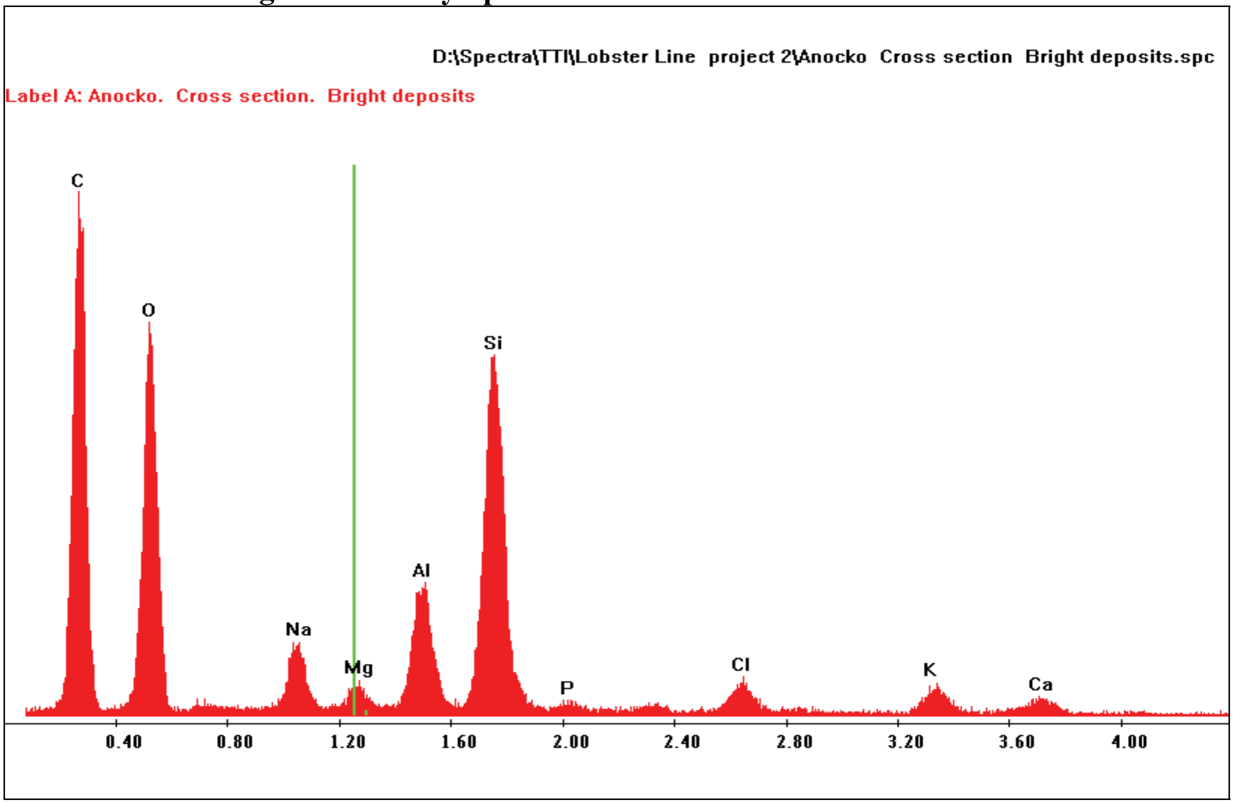


In Photograph 28, abrasion damage is evident to the outer face, with PP fibrils very easily seen. Pressure damage is seen to the inner face to both the polyester filaments [flattened] and the PP filaments, where flow is seen. PP internal abrasion damage is also seen to the PP filaments whilst the polyester filaments show little sign of internal abrasion damage.

Photographs 29, a-c, show close views of part of the cross-section with particle contamination and some filament damage due to this contamination is seen. Photographs d and e give examples of particles trapped within the filaments.

Figure 1 shows the X-ray spectrum for the particle contamination seen in Photograph 29

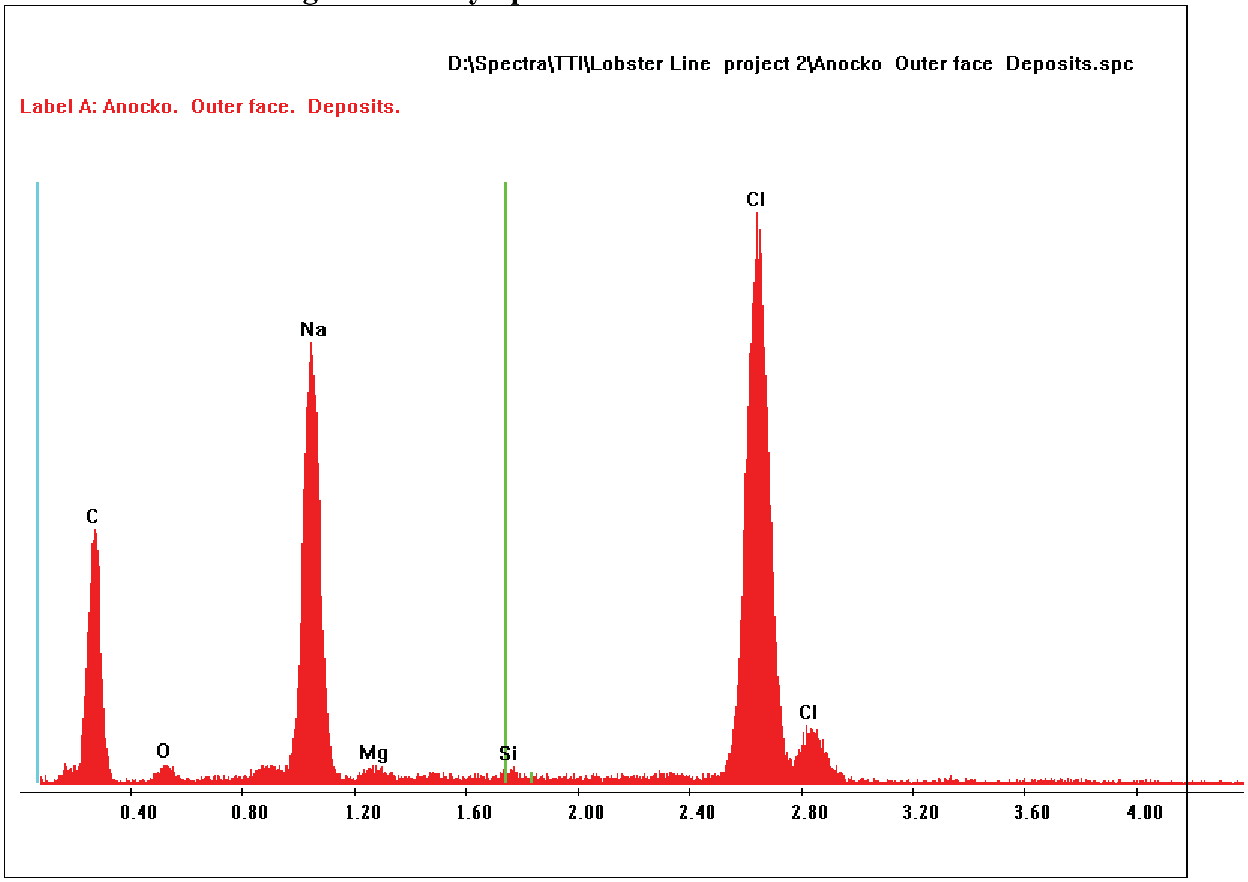
Figure 1 X-ray Spectrum of Anacko cross-section



It must be remembered this is only from one cross-section and from one small part of that cross-section. However, in this spectrum, the C and O peaks represent the polypropylene and polyester materials and the other major peak is for silicone, Si. This suggests that silica in the form of sand is the dominant particle contaminant.

Figure 2 shows a similar spectrum but from the outer layer. In this case, salt appears to be the dominant contaminant.

Figure 2 X-ray Spectrum of Anacko outer face



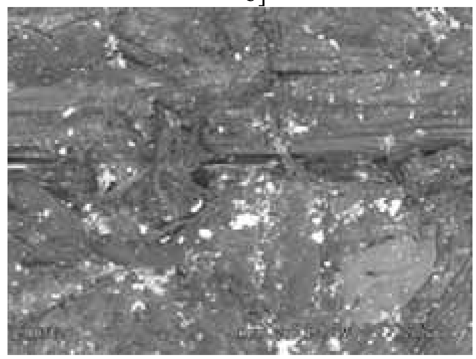
2.3.2 Everson 3-strand field rope, 31 hauls

Photograph 30

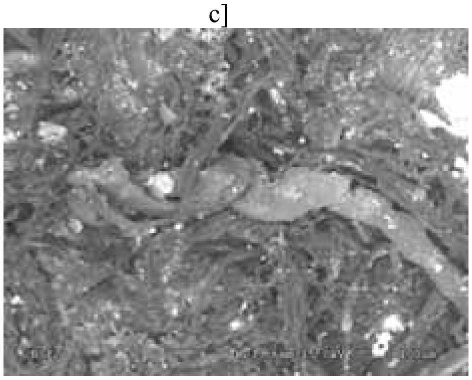
Further surface views, outer face

a]

b]



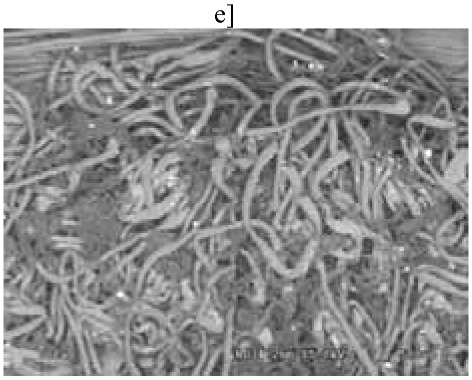
c]



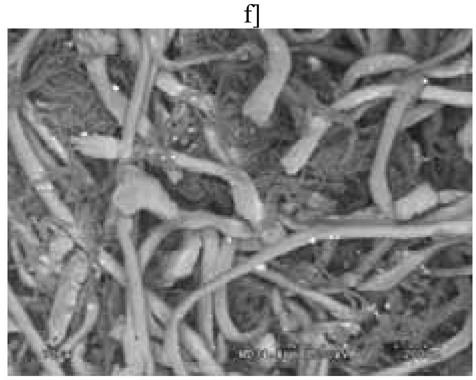
d]

Further surface views, inner face

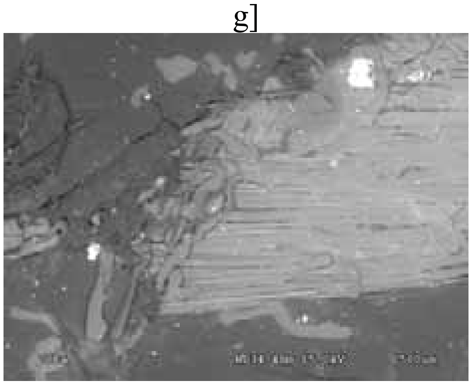
e]



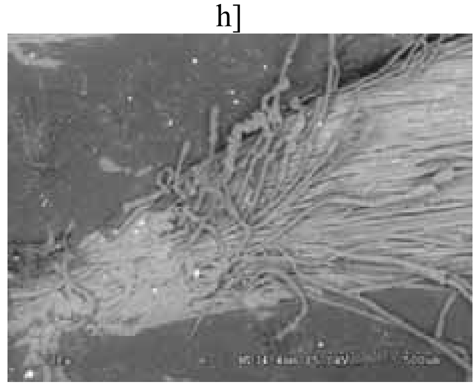
f]



g]



h]

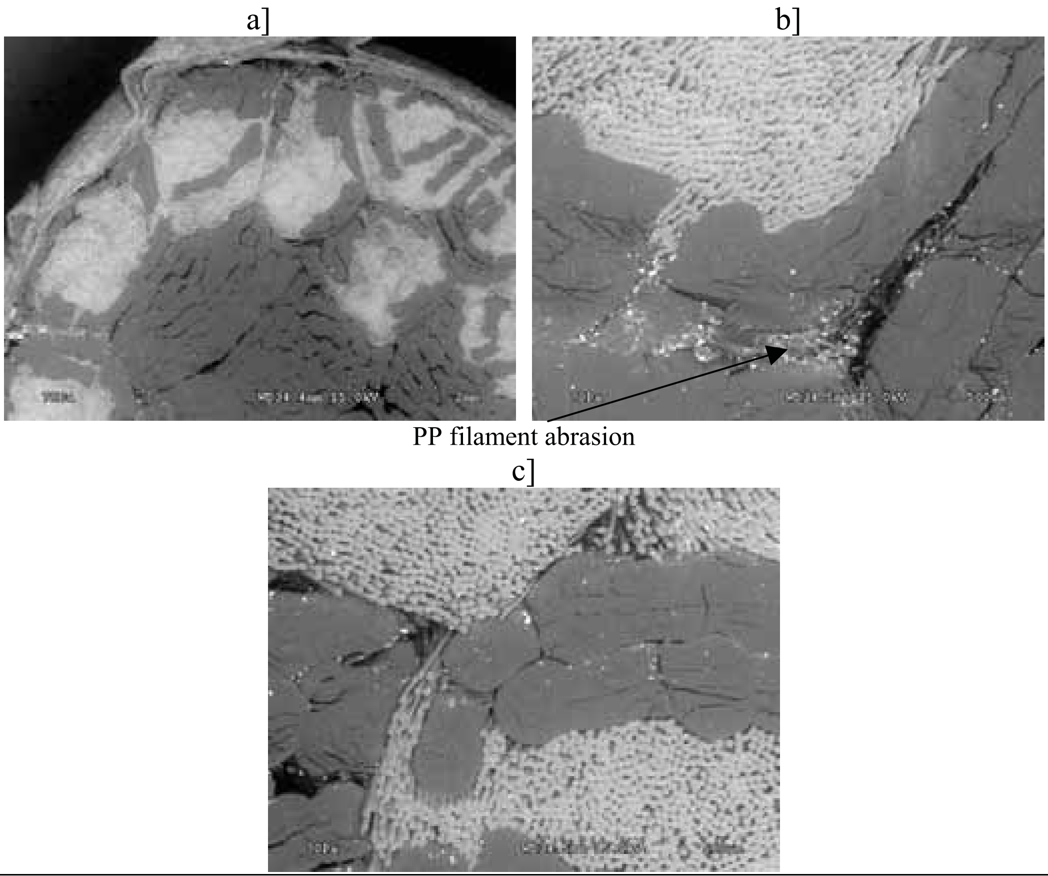


Flattened polyester filaments are seen in photograph 30a, whist photographs 30b and c show abraded PP. Photograph 30d shows what appears to be the remains of small organisms with salt crystals adjacent, both being partially embedded in flowed PP.

Photograph 31 shows close views of a cross-section of a strand.

Photograph 31

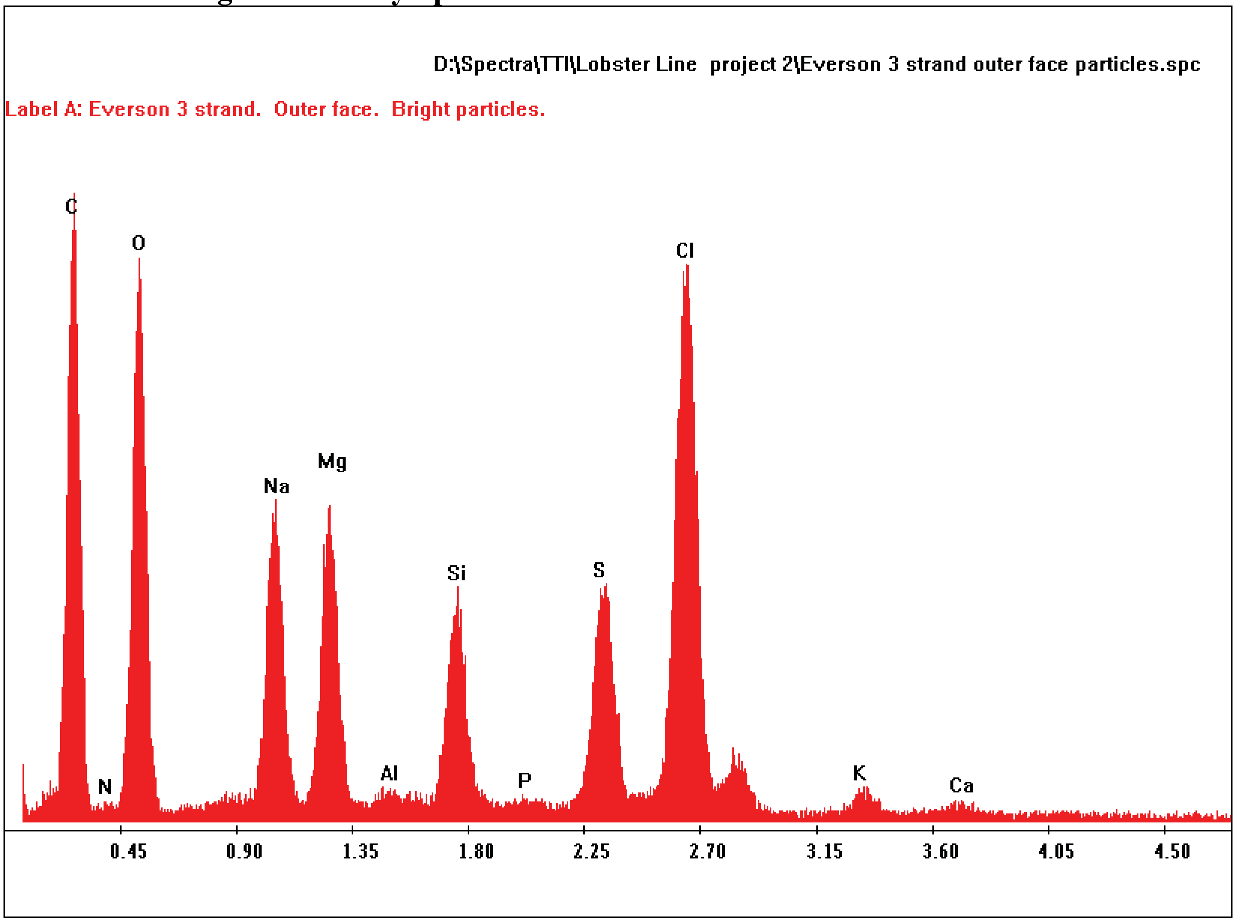
Further cross-section views



Particle penetration is mild but there is some evidence of PP filament abrasion caused by this. Although external abrasion and pressure effects are seen in the surface views, the cross-sections show that these effects do not extend into the interior of the strand. Some abrasion due to particle penetration is also seen.

Figure 3 is an X-ray spectrum of the outer face of the strand. Both sand and salt appear to be contaminants.

Figure 3 X-ray Spectrum of Everson 3-strand outer face



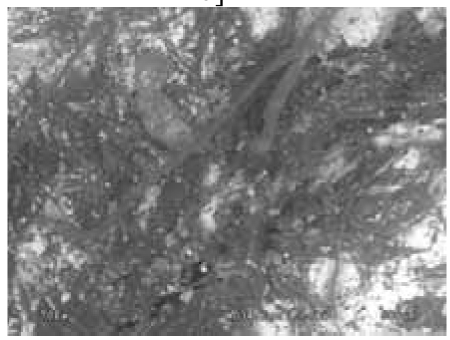
2.3.3 Everson 4-strand field rope, 43 hauls

Photograph 32

Further surface views, outer face

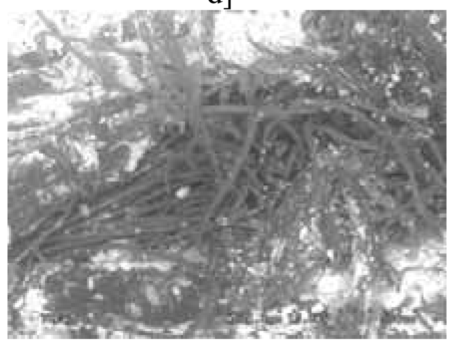
a]

b]



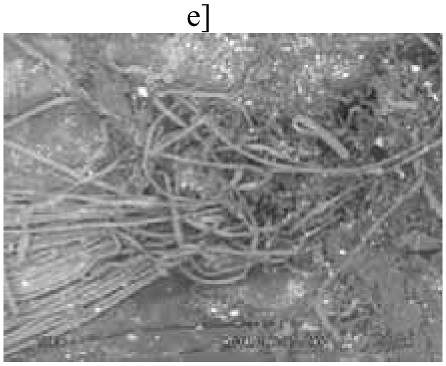
c]

d]

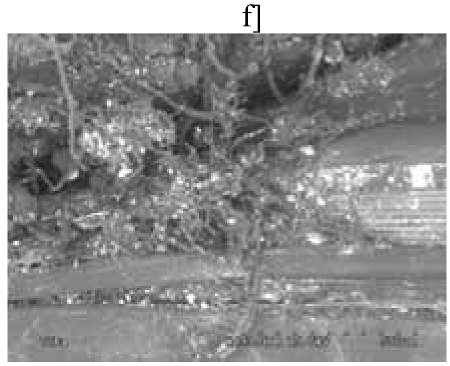


Further surface views, inner face

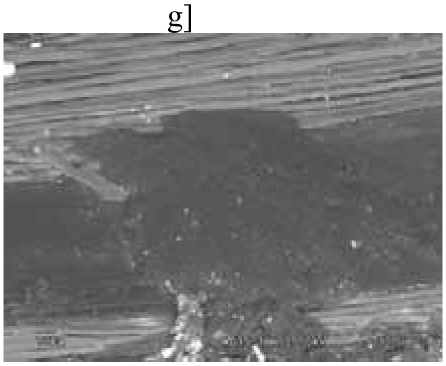
e]



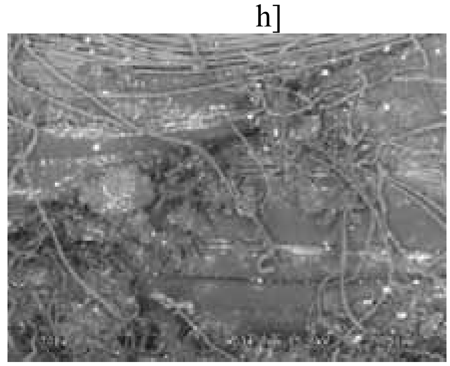
f]



g]



h]

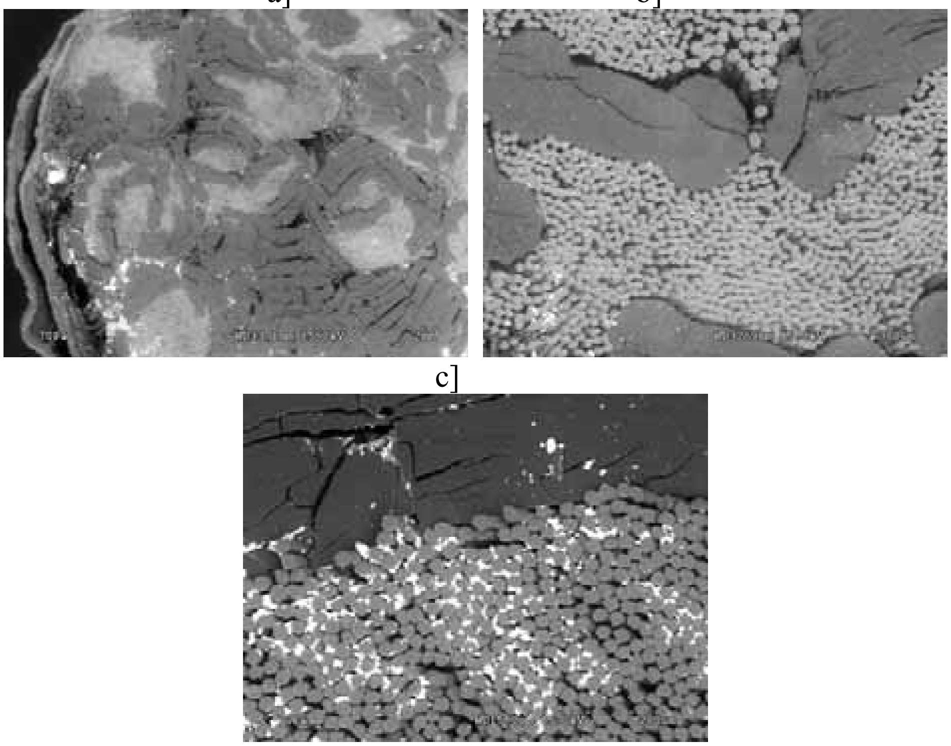


Embedded sediment is much in evidence on the outer face of this rope. Polypropylene abrasion debris and flattened polyester filaments are also seen. Very much reduced sediment is found on the inner face. Flattened PP and PP abrasion debris is seen on the inner face as well as abraded polyester filaments.

Photograph 33

Further cross-section views

a] b] c]



Photograph 33c shows little filament surface abrasion damage with either the PP or the polyester filaments, despite a reasonably high level of particle penetration.

Figures 4 and 5 show X-ray spectra for the inner and outer faces. Salt appears to be the main particle contaminant.

Figure 4

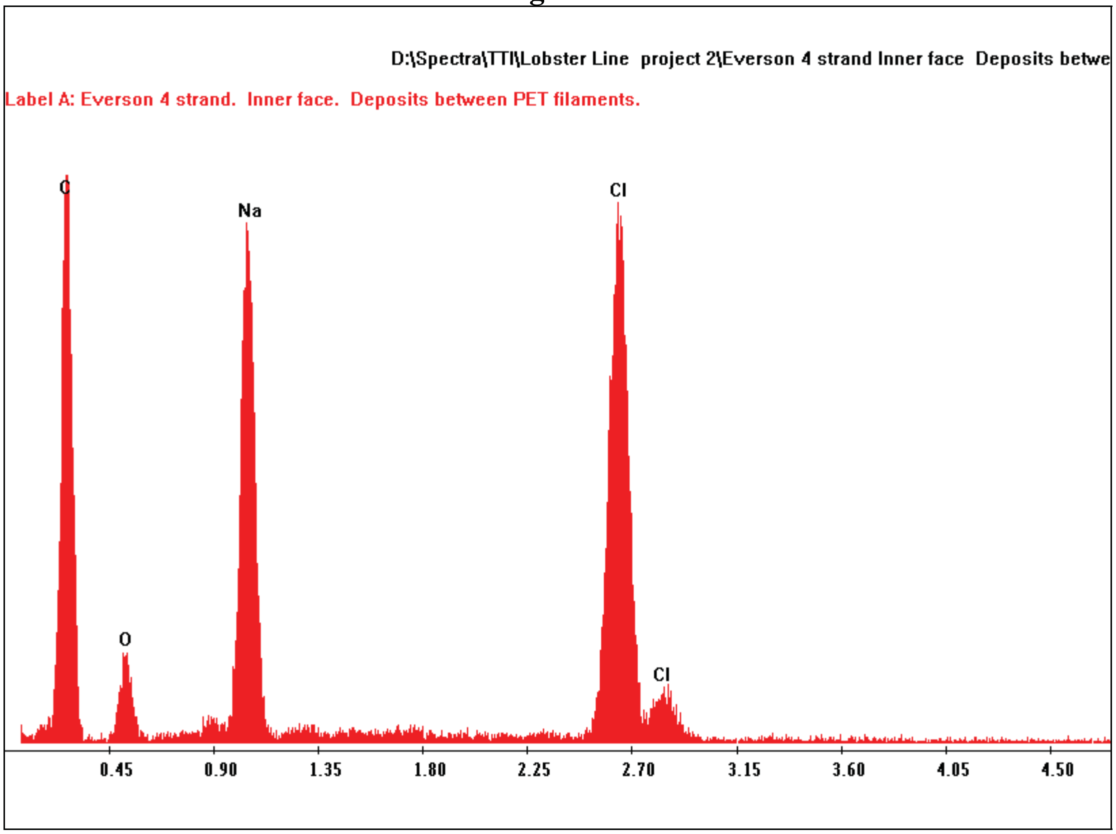
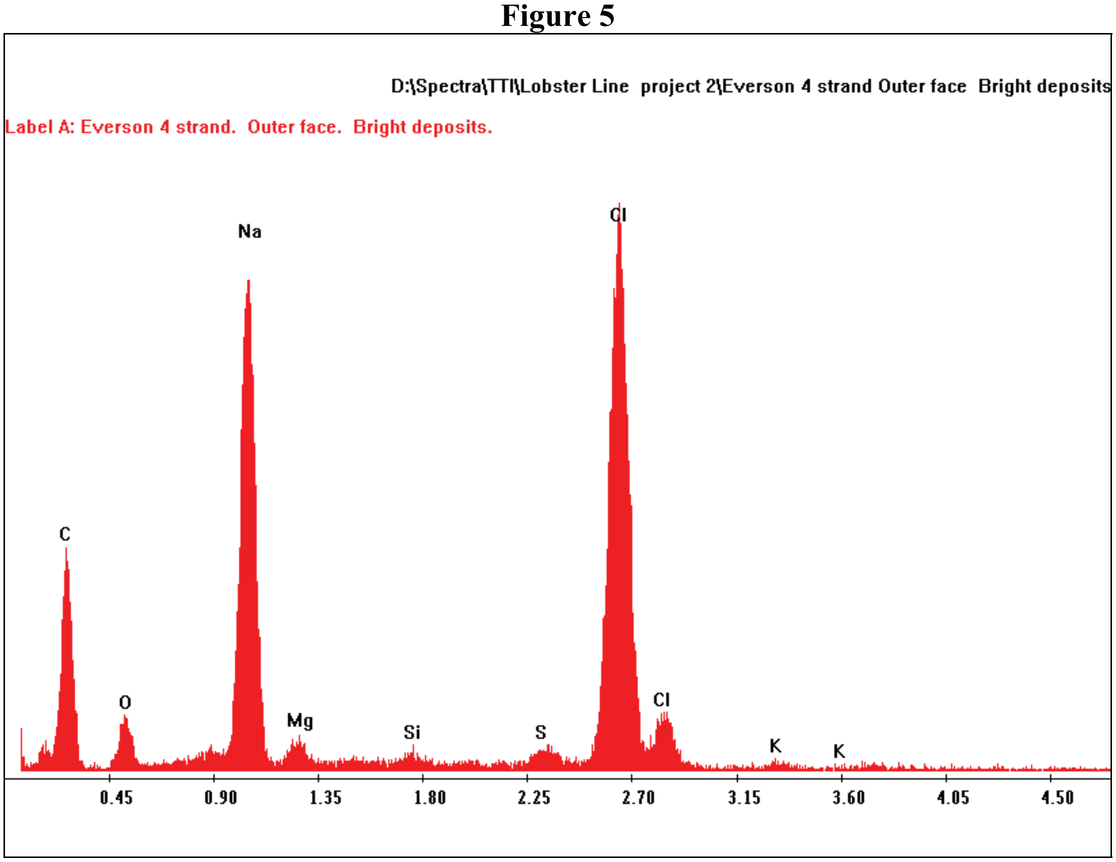


Figure 5

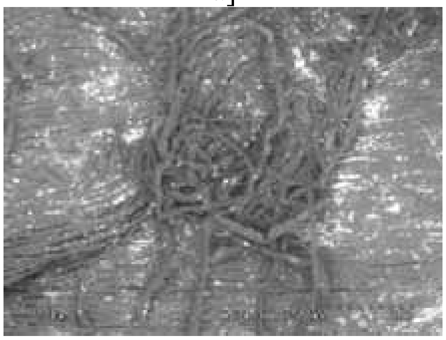


2.3.4 Orion Orco field rope, 28 hauls

Photograph 34

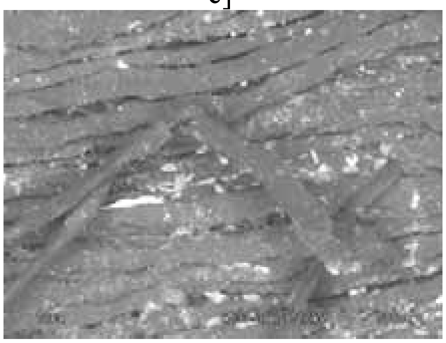
Further surface views, outer face

a]



b]

c]

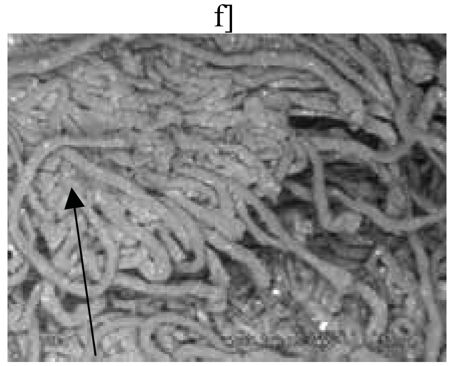


d]

Further surface views, inner face

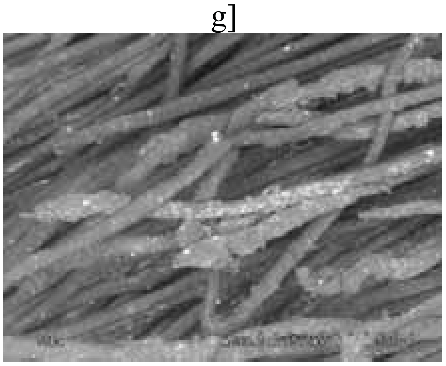
e]

f]

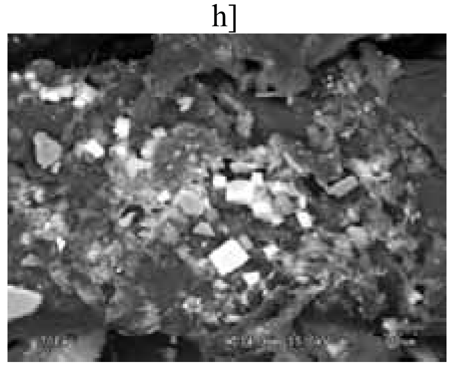


Mild melded filament clump

g]



h]

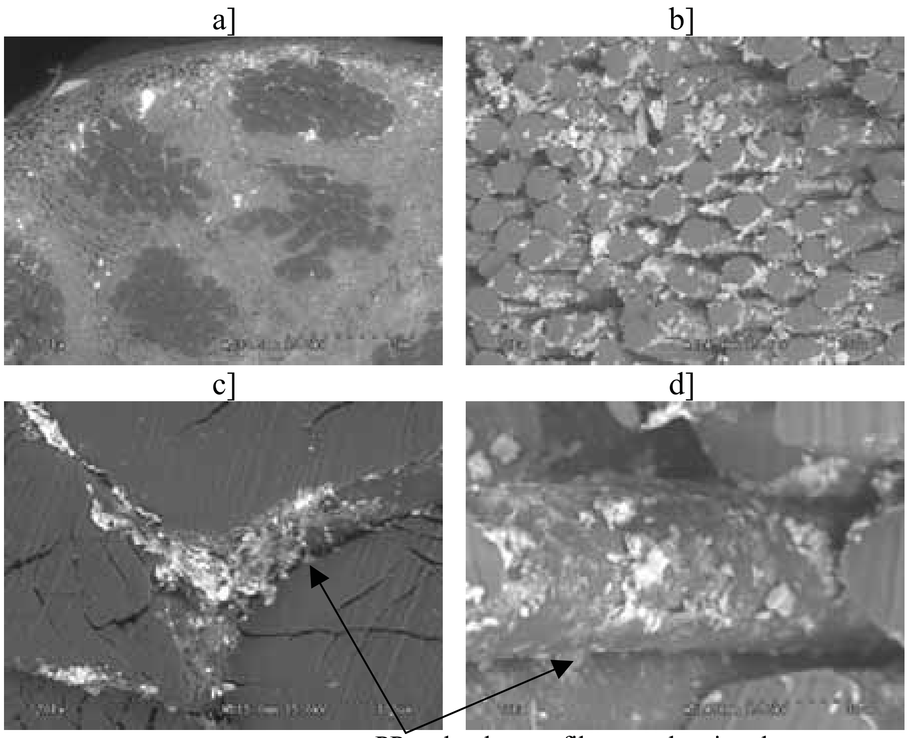


Pressure-induced flattening and abrasion damage is seen to the polyester filaments on the outer face. Less abrasion damage is seen on the inner face, whilst pressure flattening is still seen. Photograph 33h shows a clump of particle contamination.

Photograph 35 shows further views of a cross-section.

Photograph 35

Further views, cross-section



PP and polyester filament abrasion damage

Photographs 35c and d show particle penetration within the PP and polyester filaments, respectively. Some surface damage to both types of filament is seen.

Figures 6 and 7 are X-ray spectra of sediment seen on the outer and inner surfaces, whilst Figures 8 and 9 are spectra of sediment seen in the cross-section, between the PP and polyester filaments respectively.

Figure 6

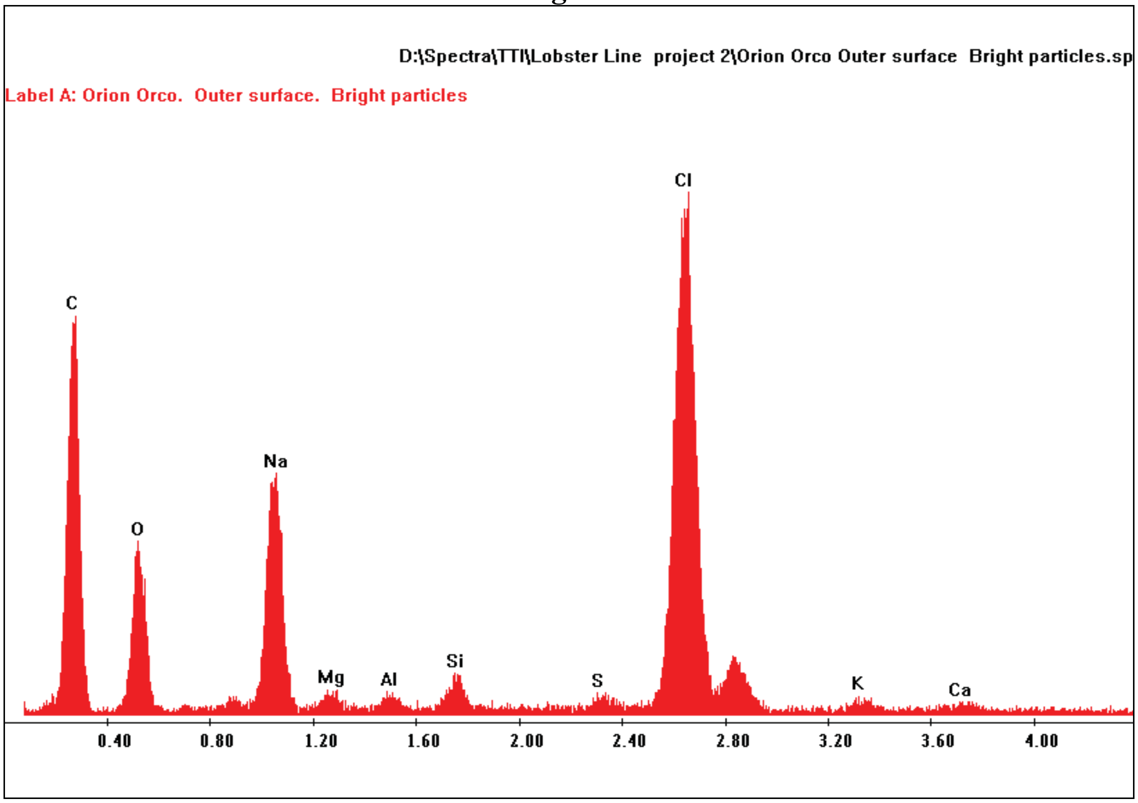


Figure 7

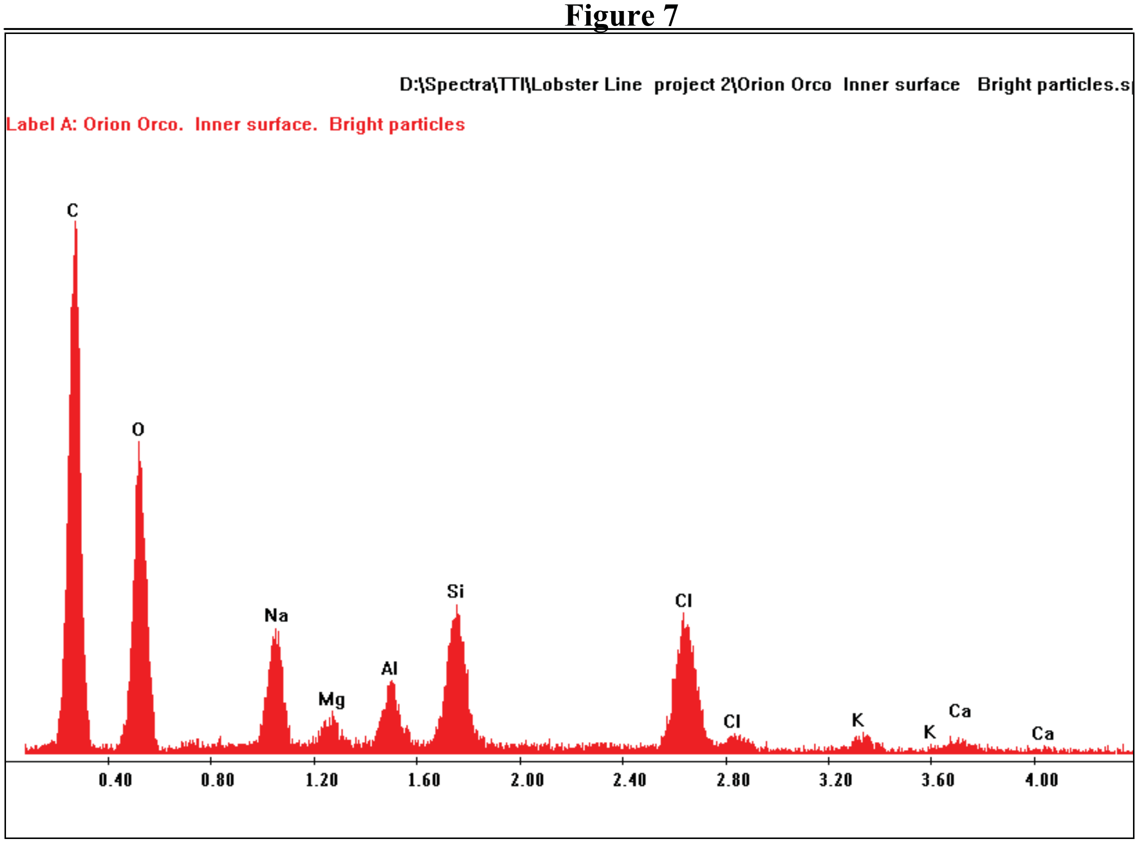


Figure 8

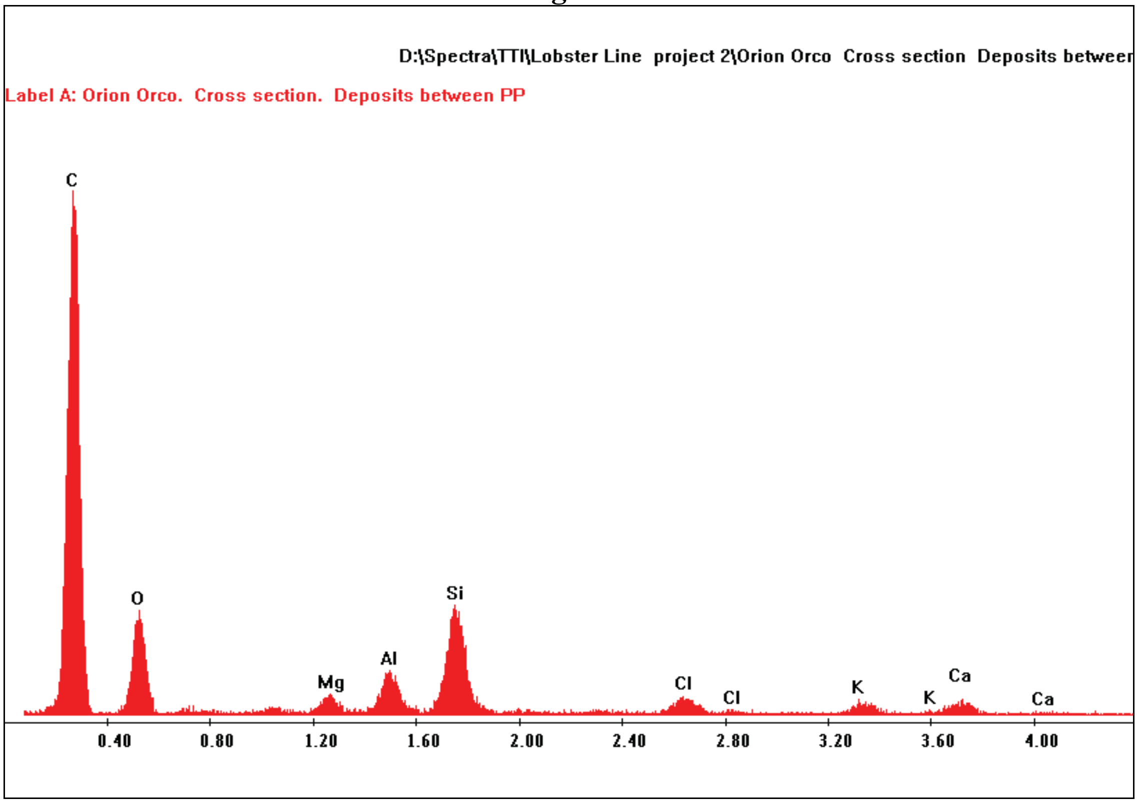
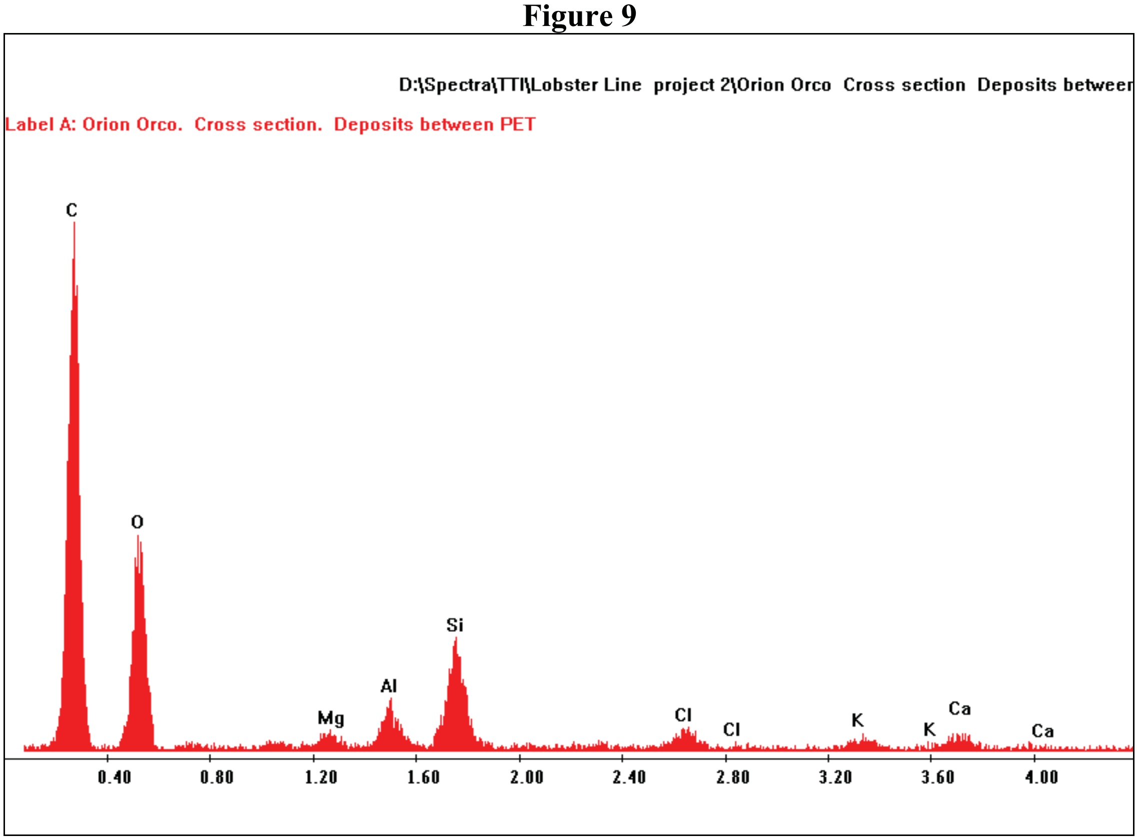


Figure 9

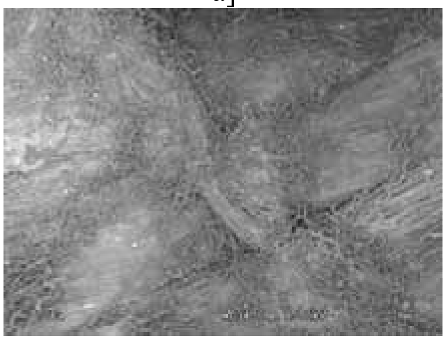


2.3.5 Polysteel Ester Pro field rope, 43 hauls

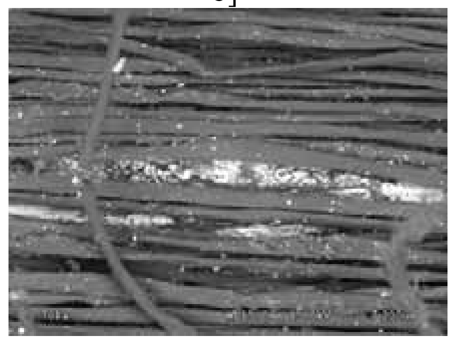
Photograph 36

Further surface views, outer face

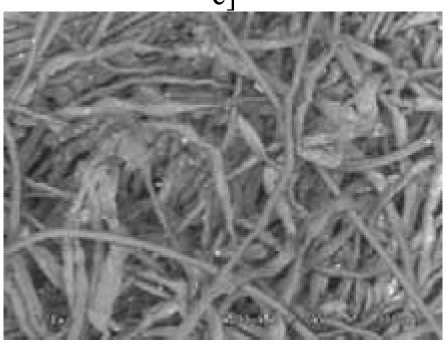
a]



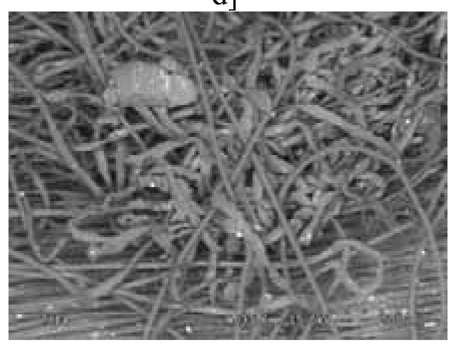
b]



c]

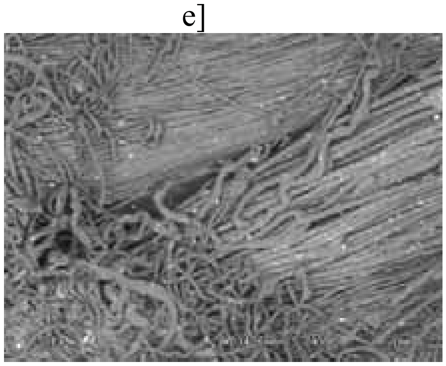


d]

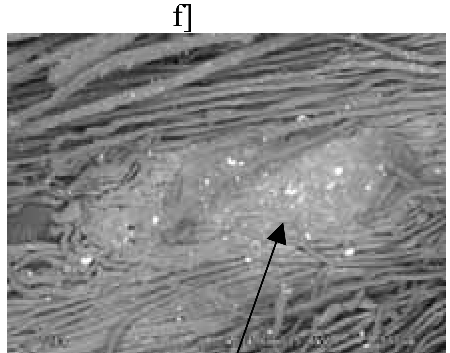


Further surface views, inner face

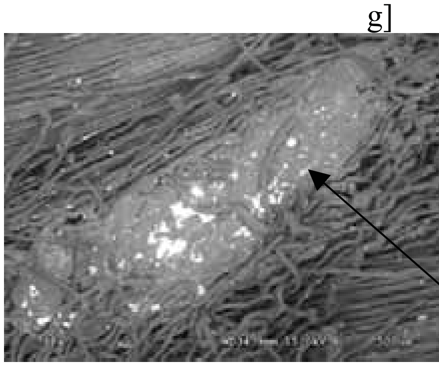
e]



f]



g]



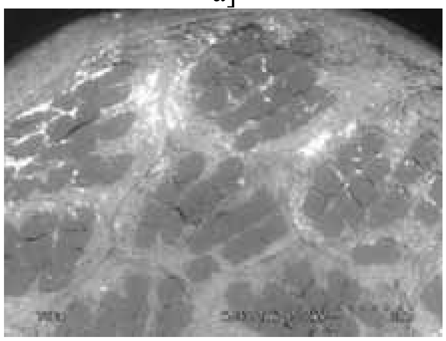
partially fused filaments.

Photograph 37 shows further cross-section views.

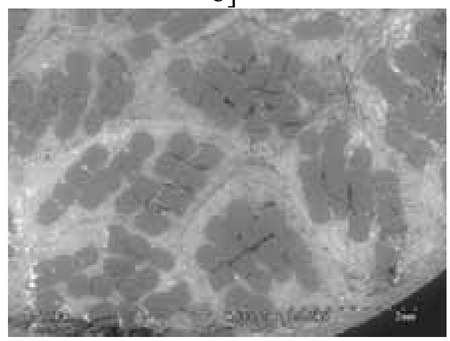
Photograph 37

Further views, cross-section

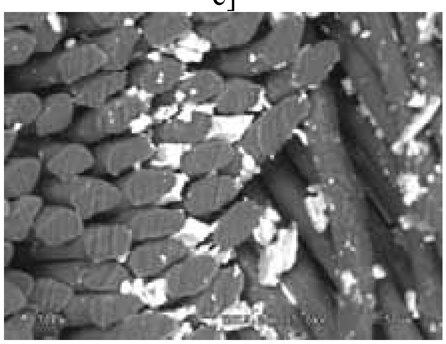
a]



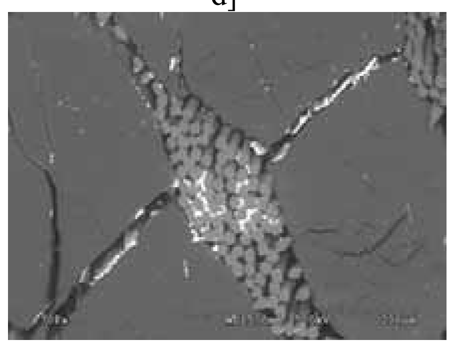
b]



c]



d]



The Ester Pro and Orco ropes have a similar method of construction, whereby core PP filaments are surrounded by polyester filaments. Comparison of the two sets of images are useful, as field reports for the Orco specification were not favourable, whilst the Ester Pro did not attract adverse comment.

Comparing the outer surface views of the two specifications, there is a general trend for the Orco rope to show greater filament flattening and breakage due to pressure. A difference between the inner surfaces is less easy to see, though there is an indication that for the Ester Pro rope may have suffered from greater internal pressure, as clumps of partially melded/fused filaments were seen. A clump of more mildly melded filaments was seen with the Orco inner surface.

In cross-section, the Orco specification does show evidence of filament surface damage to both filament types where sendiment/particles are present whilst for the Ester Pro specification, this is much less obvious.

Figures 9,10 and 11 show X-ray spectra of deposits on the outer and inner faces and the cross-section.

Figure 9

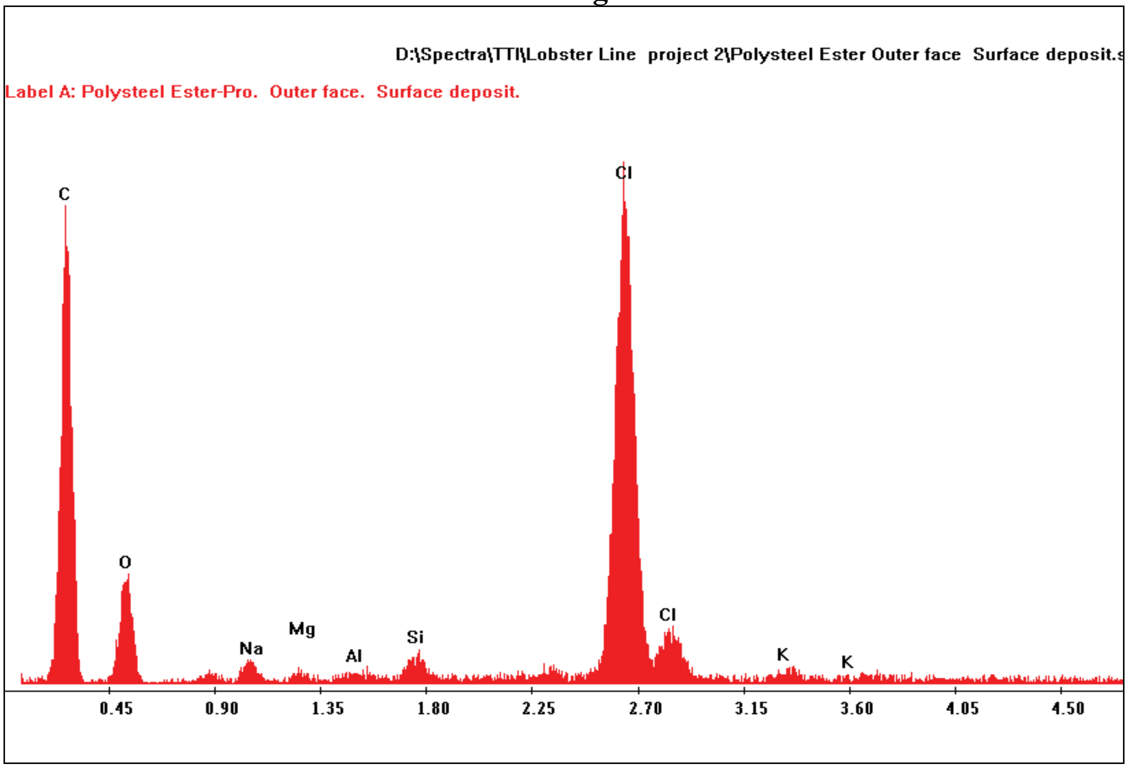


Figure 10

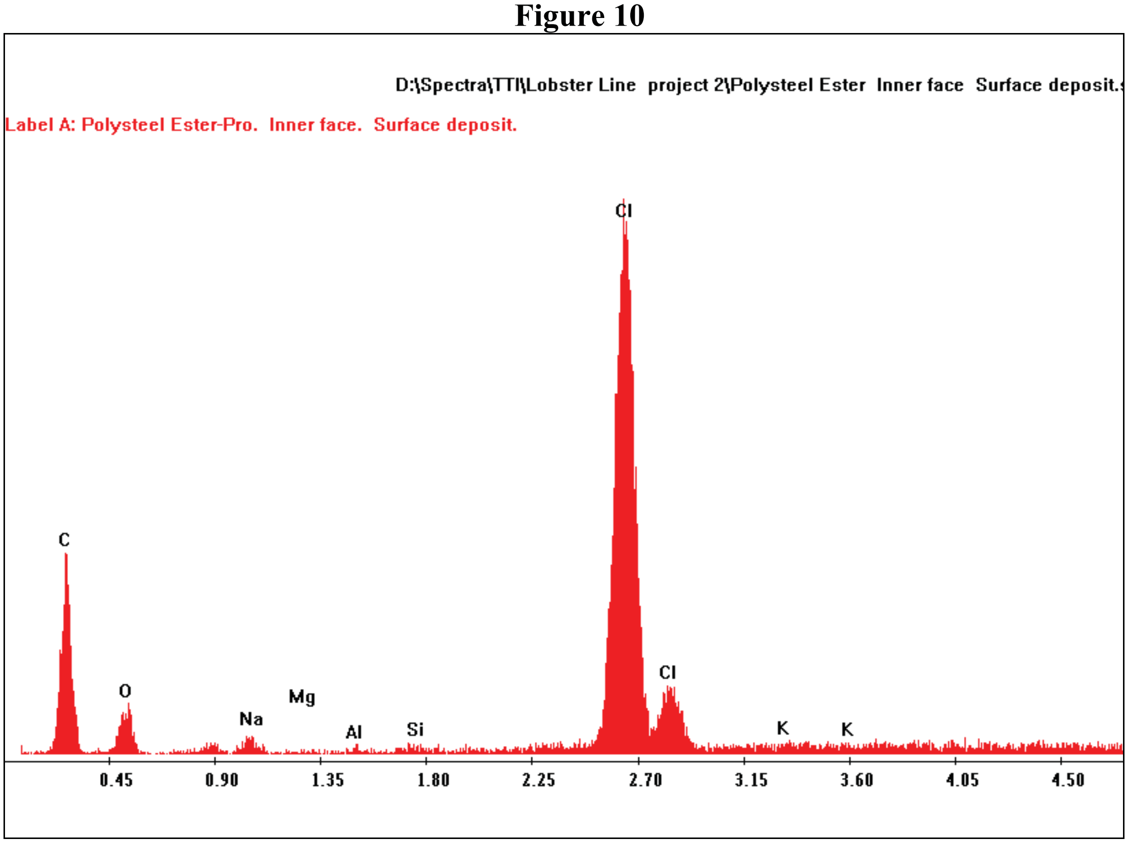
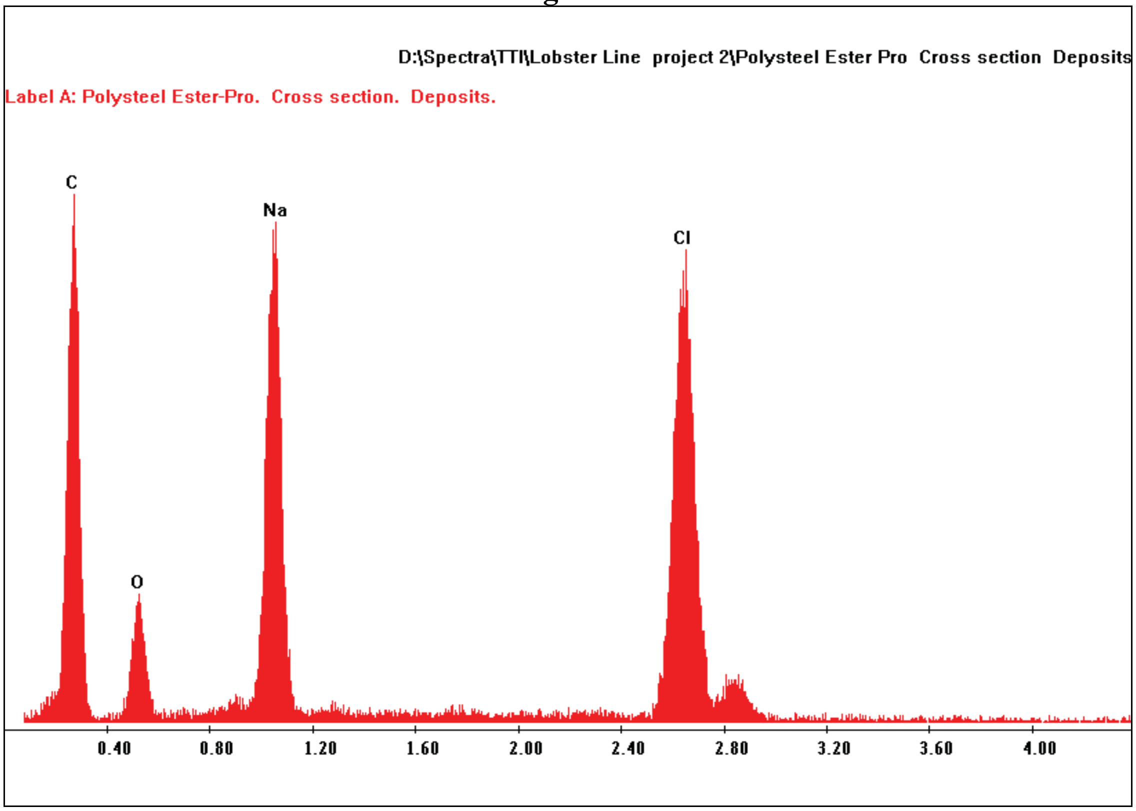


Figure 11



Salt appears to be the main component of the sediment, though it can be seen that sodium, Na, was not strongly identified in the spectra of Figures 9 and 10.

A review of the complete set of X-ray spectra does not reveal any particular trend in terms of the behaviour of sediment either on the surface or through the cross-section of the different ropes.

2.3.6 Conclusions from the visual and SEM investigations

The ropes had been subjected to different numbers of hauls in different locations. Also, there may also have been differences in the gear used to work the lines. However, based on the samples received, the following observations and conclusions can be made:

1. One of the ropes, supplied by Anacko, had PP filaments predominantly to the outer face of the rope strands. Rope supplied by Orion [Orco] and Polysteel [Ester Pro] had predominantly polyester filaments to their strand outer faces. The remaining two specifications were supplied by Everson, and strand outer faces consisted of blends of polyester and PP filaments.
2. Surface abrasion, both internal and external, is the dominant mechanisms for damage to the ropes.
3. The effect of pressure is also clearly seen, particularly on inner faces of strands, where deformation and material flow can be seen. The PP filaments, with their

lower melting points, were seen to be more susceptible to the effect of pressure than were the polyester filaments.

4. Damage to the inner structure of the rope strands, due to the abrasive effect of sediment was not a major contributor to damage, though it was seen in three rope specifications, Orion Orco and Everson 3-strand and Anacko.
5. The best performing specification from this group of ropes is one where the outer layer of a rope strand is made from rope yarns that are themselves a blend of coarse PP filaments and finer polyester filaments. The presence of the lower melting point PP in the surface appears to reduce the adverse abrasion effects caused by running the ropes through hauling gear. In this series of trials, this type of rope was produced by Everson, as a 3 or 4-strand design.
6. Where polyester filaments dominate the outer face, Orion Orco and Polysteel Ester Pro, the Orion specification appears to have suffered a greater degree of abrasion and pressure damage.
7. Where PP filaments are dominant on the strand surfaces, Anacko, mechanical breakage of the filaments, due to abrasion, is very evident.
8. No particular trend was seen with regard to the type of particle found and to where it migrated throughout the cross-section of a strand.

3 TENSILE TESTING and ESTIMATE OF RESIDUAL ROPE STRENGTH

Table 4 shows samples received by TTI that were used in the tensile test programme.

Table 4 List of ropes tensile tested at TTI

Rope	New	Machine	Field
Anacko, L10	No	No	Yes
Everson 3-strand, L1	Yes	No	Yes
Everson 4-strand, L2	Yes	No	Yes
Orion Orco, L13	No	Yes	Yes
Polysteel Ester Pro, L16	Yes	Yes	Yes

Table 5 is a summary of the whole rope [new and machine tested] tensile test results reported by DMF

Table 4 Whole rope tensile results from DMF [Kenney grip]

Rope	Breaking Load, lbf		
	New	Machine	Field
Anacko, L10	8938	4182	No
Everson 3-strand, L1	9658	5745	No
Everson 4-strand, L2	10196	5381	No
Orion Orco, L13	9442	5154	No
Polysteel Ester Pro, L16	9419	5113	No

From these results, the % Residual Strength is easily calculated and shown in Table 5

Table 5 Residual Strength of machine tested ropes

Rope	% Residual Strength
Anacko, L10	46.8
Everson 3-strand, L1	59.5
Everson 4-strand, L2	52.8
Orion Orco, L13	54.6
Polysteel Ester Pro, L16	54.3

It can be seen that the Anacko specification has suffered the greatest loss of strength, whilst the best rope in terms of Residual Strength is the Everson 3-strand specification.

Table 6 shows the results of the strand testing performed at TTI

Table 6 Strand Breaking Load test results

Rope	New			Machine			Field		
	BL lbf	SD lbf	CV %	BL lbf	SD lbf	CV %	BL lbf	SD lbf	CV %
Anacko	-	-	-	-	-	-	**2598**	48	1.8
Everson 3-strand	**4351**	52	1.2	-	-	-	**3047**	79	2.6
Everson 4-strand	**3027**	176	5.8	-	-	-	**2538**	66	2.6
Orion Orco	-	-	-	**2535**	188	7.4	**2048**	68	3.3
Polysteel Ester Pro	**3939**	287	7.0	**1137**	248	22	**3093**	309	10.0

DMF have confirmed that the machine abrasion testing was designed to produce wear on the rope equivalent to several seasons of use, whilst the field rope samples have only had one season of use.

It can be seen that there are unusual results for the Orion Orco specification, in that the field strand strength results are less than the machine strand strength results despite the fact that the machine test is more severe. However, it was found during the SEM investigation that the field and machine samples from Orion appeared to have different constructions, in that the field sample had more polyester filament material than the machine tested version. The filament diameters also appeared to be different. The Orco field sample was not well-received by the fishermen but no adverse reports for the machine-tested sample have been received by TTI.

It is possible to estimate the Realisation Factor that may be used to estimate the Residual Strength of the field tested ropes from the following calculation:

$$\text{Realisation Factor [RF]} = \frac{\text{New whole rope strength}}{[\text{new strand strength x no of strands}]}$$

The RF can be calculated for the Everson 3 and 4 strand specifications and the Polysteel Ester Pro specification, shown in Table 7

Table 7 Realisation Factors for new ropes

Rope	Realization Factor
Everson 3-strand	0.740
Everson 4-strand	0.842
Polysteel Ester Pro	0.797

The average value for the RF is 0.793, and this is a reasonable value to use for strand-to-rope Residual Strength calculations. It is used to estimate the % Residual Strength of the field tested ropes as shown in Table 8.

Table 8 Estimated % Residual Strength of the field tested ropes

Rope	Strand strength lbf	No of strands	Total strength lbf	Realisation Factor	Estimated Rope Strength lbf	% Residual Strength
Anacko	2598	3	7794	0.793	6181	69.2
Everson 3-strand	3047	3	9141	0.793	7249	75.1
Everson 4-strand	2538	4	10153	0.793	8051	79.0
Orion Orco	2048	3	6144	0.793	4872	51.6
Polysteel Ester Pro	3093	3	9279	0.793	7358	78.1

The low Orion results are a direct reflection of the tensile test results for the strands. The possible reason for this odd result has already been discussed.

The Anacko specification has lowest % Residual Strength and the result is in line with the visual appearance of the rope, where significant abrasion damage was seen. It is also in line with the Kenney results from whole rope testing of new and machine tested ropes.

Whilst the Everson 4-strand specification has the highest estimated Residual Strength, within the limits of the testing that could be performed, there is little to differentiate the two Everson specifications and the Polysteel specification.

4 CONCLUSIONS

The Orion study appears to have been compromised by the use of ropes of differing specifications in field and machine testing. However, the difference found may help to explain the poor performance of the field rope experienced by the fishermen.

Visual inspection of the Anacko rope showed severe mechanical damage to the outer surface of the rope, caused by external abrasion. This damage was reflected in a lower % Residual Strength and suggests that a rope construction that has a predominance of PP in the surface is less tolerant to external abrasion than a construction that has a blend of PP and polyester in the outer surface.

The Everson specifications, with a blend of PP and polyester filaments in their outer surface, performed well both in the field and in the laboratory testing at TTI.

It is difficult to make an assessment of a rope having a predominance of polyester filaments in its surface, as the results of the Orion and the Polysteel studies are contradictory. The Orion specification was the worst performing specification [both in the TTI laboratory and in the field] of all the ropes studied, whilst the Polysteel rope had a performance similar to the Everson specifications. However, analysis is difficult because of the doubt over the construction of the Orion Orco rope.

External and internal abrasion was the dominant fatigue mechanism, but there was much evidence of pressure damage to the PP and polyester filaments. The PP filaments tended to fibrillate under abrasion and to flow and fuse under pressure. It is this behaviour under pressure that may have contributed to its good abrasion resistance performance, as the PP could have had a lubrication effect.
